# TRANSACTIONS

of the

# American Foundrymen's Association

Proceedings of the

**Thirty-eighth Annual Meeting**

Philadelphia, Pa.

October 22 to 26, 1934

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## VOLUME XLII

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EDITED BY
ROBERT E. KENNEDY and NORMAN F. HINDLE

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of the

# American Foundrymen's Association

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# Summary of Proceedings of the 38th Annual Meeting

THE Thirty-Eighth Annual Convention of the American Foundrymen's Association was held October 22-26, 1934, at the Convention Hall, Philadelphia. This meeting was also designated at the Fifth International Foundry Congress. An Exposition of Foundry Equipment and Supplies was held at the same time under the auspices of the A.F.A.

The great enthusiasm displayed by those in attendance, the excellence of the program, and the exhibits all contributed to make this congress one of the most successful ever held. The registration exceeded 3500, which figure, while not the largest attendance record of the Association's history, yet considering the industrial conditions existing, far surpassed the anticipation of the Association's officers.

With President Frank J. Lanahan presiding, the meeting was especially noteworthy from all aspects, while the presence of about 100 overseas guests, under the leadership of Joseph Leonard, Acting President of the International Committee of Foundry Technical Associations, and the presentation of seven papers from foreign associations, made the Congress an outstanding success from the international viewpoint. The official delegates from overseas countries were:

ASSOCIATION TECHNIQUE DE FONDERIE DE BELGIQUE.
Joseph Leonard, Grivegnee.

ASSOCIATION TECHNIQUE DE FONDERIE DE FRANCE.
A. Brizon, Courbevoie (Seine).

GERMAN FOUNDRYMEN'S ASSOCIATION.
Dr. Eugen Piwowarsky, Aachen.
Otto J. Schleimer, Reimsheid.

INSTITUTE OF BRITISH FOUNDRYMEN.
T. Makemson, Manchester.

BRITISH IRON AND STEEL INSTITUTE.
H. Spence Thomas, London.

BRITISH CAST IRON RESEARCH ASSOCIATION.
J. B. Allen, Chesterfield.

NATIONAL IRONFOUNDERS EMPLOYERS' FEDERATION.
James Smith, Durham, England.

DIVISION OF ITALIAN STEEL FOUNDRYMEN.
Dr. Luigi Norsa, Milano.
Dr. Guido Vanzetti, Milano.

POLISH FOUNDRYMEN'S ASSOCIATION.
Witold W. Kosicki.

SPANISH COMMITTEE ON TESTING MATERIALS.
Dr. Jose Navarro Alcacer, Valencia, Spain.

Exchange papers were contributed on behalf of the foundry associations of Great Britain, France, Czechoslovakia, Germany, Italy, Belgium and Spain.

Two of the fourteen regular technical sessions were held jointly with other technical associations. A session on Testing Cast Iron was sponsored with the American Society for Testing Materials and a Conference on Pattern Making was sponsored with the American Society of Mechanical Engineers, Division of Wood Industries.

Each Division held a round table luncheon conference and two four-session shop courses were presented, one on cast iron and one on sand control.

An outstanding feature of the convention was the innovation of a special lecture on a general interest subject. This lecture was given by Arnold Lenz, 1934 A.F.A. medallist, his subject being "Foundry Progress." Mr. Lenz's address was published in TRANSACTIONS, vol. V, no. 5, October 1934, pp. 42-58.

The alumni dinner, attended by the officers and members of the Board, past officers and a group of "Old Timers" who were present at the organization convention in 1896, was made the occasion for honoring John A. Penton, the first secretary of the Association, who was principally responsible for the organization of the Association. Past President Utley reviewed Mr. Penton's connection with the Association, his address appearing in TRANSACTIONS, vol. V, no. 5, October 1934, pp. 17-23. It was notable that on this occasion twelve past presidents were in attendance.

A concluding feature of the convention was the inspection trip to the Bethelehem Steel Company plant at Bethlehem, Pa. A special train was arranged by the Philadelphia Foundry Committee and some three hundred members made the trip, which took place the afternoon of the last day of the convention.

# Fifth International Foundry Congress

## OPENING SESSION

*Tuesday, October 23, 10:00 A.M.*

*Presiding:* Frank J. Lanahan, President, American Foundrymen's Association. (A detailed account of this session appears in TRANSACTIONS, vol. V, no. 5, October 1934, pp. 7-8.)

President Lanahan, in opening the Fifth International Congress introduced the Hon. J. Hampton Moore, Mayor of the City of Philadelphia, who gave an address of welcome to the assembled members and guests of the Association. President Lanahan then presented the annual presidential address.

Tom Makemson, Honorary Secretary of the International Committee of Foundry Technical Associations, was then requested to call the roll of foreign associations represented and to introduce the leader of each delegation. This was done and the responses in foreign languages were translated and re-presented by Vincent Delport, European Representative of the A.F.A.

Messages of greeting from the Institute of British Foundrymen and the Association Technique de Fonderie de France were read by Vice President Dan M. Avey.

## SAND CONTROL SHOP OPERATION COURSE (Session 1)

*Monday, October 22, 2:30 P.M.*

*Chairman*—A. V. Leun, Bethlehem Steel Co., Bethlehem, Pa.

Application of Sand Control to Continuous and Jobbing Foundries. *Discussion Leader*—L. B. Knight, Jr., National Engineering Co., Chicago.

## GRAY IRON SHOP OPERATION COURSE (Session 1)

*Monday, October 22, 4:00 P.M.*

*Chairman*—P. T. Bancroft, John Deere Harvester Works, East Moline, Ill.

General Cupola Practice. *Discussion Leader*—W. H. Spencer, American Cast Iron Pipe Co., Birmingham, Ala.

## SAND CONTROL SHOP OPERATION COURSE (Session 2)

*Tuesday, October 23, 9:00 A.M.*

*Chairman*—Dr. H. Ries, Cornell University, Ithaca, N. Y.

Classification of Foundry Sands. *Discussion Leader*—H. W. Dietert, U. S. Radiator Corp., Detroit.

### NONFERROUS FOUNDING

*Tuesday, October 23, 2:30 P.M.*

*Chairman*—Sam Tour, Lucius Pitkin, Inc., New York, N. Y.

*Vice Chairman*—Jerome Strauss, Vanadium Corp. of America, Bridgeville, Pa.

The following papers were read and discussed:

*Effects of Elevated Temperature on the Strength and Dimensional Stability of Certain Aluminum Alloys Used in Aircraft*, R. R. Kennedy, Wright Field, Dayton, Ohio.

*Porosity in Leaded Bronze Bushings*, A. W. Lorenz (deceased). This paper was presented by Knight Charlton, Bucyrus-Erie Co., Milwaukee, Wis.

*Cupola Melting of Red Brass*, W. C. Alvin, Imperial Brass Mfg. Co., Chicago. In the absence of the author this paper was presented by R. L. Binney, Binney Castings Co., Toledo, Ohio.

### NONFERROUS DIVISION BUSINESS SESSION

Chairman Tour read the report of the Division's Nominating Committee, following which the following officers and members of the Advisory Committee were elected:

*For Chairman to Serve for Two Years:*
Jerome Strauss, Vanadium Corp. of America, Bridgeville, Pa.

*For Vice Chairman to Serve for Two Years:*
John W. Bolton, Lunkenheimer Co., Cincinnati, Ohio.

*For Members of the Advisory Committee to Serve for Four Years:*
E. H. Dix, Jr., Aluminum Co. of America, New Kensington, Pa.
Wm. Romanoff, H. Kramer Co., Chicago.
C. M. Saeger, Jr., Bureau of Standards, Washington, D. C.

The report of the Program Committee was presented by R. L. Binney.

The report of the Recommended Practice Committee was presented by Jerome Strauss.

### STEEL FOUNDING

*Tuesday, October 23, 2:30 P.M.*

*Chairman*—R. A. Bull, Consultant on Steel Castings, Chicago

*Controlled Directional Solidification*, George Batty, Steel Castings Development Bureau, Philadelphia.

*Studies on Solidification and Contraction of Steel Castings; II—Free and Hindered Contraction of Cast Carbon Steel*, C. W. Briggs and R. A. Gezelius, U. S. Naval Research Laboratories, Washington, D. C. Presented by Mr. Briggs.

### APPRENTICE TRAINING

*Tuesday, October 23, 2:30 P.M.*

*Chairman*—E. H. Ballard, General Electric Co., West Lynn, Mass.

*The Necessity for Training Apprentices at the Present Time*, Kenneth Coolbaugh, Pennsylvania Dept. of Labor and Industry, Philadelphia.

*What the Government Is Doing About Apprenticeship*, W. F. Patterson, Executive Secretary, Federal Committee on Apprentice Training, Washington, D. C.

GRAY IRON SHOP OPERATION COURSE (Session 2)

*Tuesday, October 23, 4:00 P.M.*

*Chairman*—Garnet Phillips, Frank Foundries Corp., Moline, Ill.

*Cupola Fore Hearths*, G. S. Evans, Mathieson Alkali Works, New York, N. Y.

SAND CONTROL SHOP OPERATION COURSE (Session 3)

*Wednesday, October 24, 9:00 A.M.*

*Chairman*—R. F. Harrington, Hunt-Spiller Mfg. Corp., Boston, Mass.

Sand Defects: Causes and Remedies. *Discussion Leader*—J. A. Sweeney, Florence Pipe Foundry & Machine Co., Florence, N. J.

SYMPOSIUM ON POROSITY IN STEEL CASTINGS

*Wednesday, October 24, 10:00 A.M.*

*Chairman*—F. A. Melmoth, Detroit Steel Casting Co., Detroit, Mich.

R. C. Woodward, Geo. H. Smith Steel Casting Co., Milwaukee.
C. E. Sims, American Steel Foundries, East Chicago, Ind.
George Batty, Steel Castings Development Bureau, Philadelphia.
R. A. Bull, Consultant on Steel Castings, Chicago.

SYMPOSIUM ON DEOXIDATION AND DEGASIFICATION OF NONFERROUS CASTING ALLOYS

*Wednesday, October 24, 10:00 A.M.*

*Chairman*—T. E. Kihlgren, International Nickel Co., Bayonne, N. J.

*Vice Chairman*—C. H. Lorig, Battelle Memorial Institute, Columbus, Ohio

*Introduction—Discussion of General Principles*, C. H. Lorig, Battelle Memorial Institute, Columbus, Ohio.

*Red Brass and Bronze*, Committee report presented by Chairman O. W. Ellis, Ontario Research Foundation, Toronto, Canada.

*Yellow Brass Castings Alloys*, L. Ward, Chase Brass & Copper Co., Waterbury, Conn.

*Aluminum and Its Alloys*, H. J. Rowe, Aluminum Co. of America, Cleveland.

CAST IRON FOUNDING

*Wednesday, October 24, 10:00 A.M.*

*Chairman*—J. T. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala.

*Vice Chairman*—R. F. Harrington, Hunt-Spiller Mfg. Corp., Boston, Mass.

*Breaking Strength and Physical Properties of Gray Iron*, J. Novarro-Alcacer, Valencia, Spain. (Spanish Exchange Paper.)

*High Chromium Cast Iron*, G. Phillips, Frank Foundries Corp., Moline, Ill.

*Certainty of Results as the Basis in Manufacture of High-Grade Cast Iron*, E. Piwowarsky, Technical High School, Aachen, Germany. (German Exchange Paper.)

*Permanent Mold Castings*, Fred J. Walls, Eaton-Erb Foundry Co., Detroit.

*Study of the Fluidity of Cast Iron*—Report of Committee of Belgian Research Foundation. (Belgian Exchange Paper.) Presented by W. H. Spencer, American Cast Iron Pipe Co., Birmingham, Ala.

### NONFERROUS ROUND TABLE LUNCHEON

*Wednesday, October 24, 12:30 P.M.*

*Chairman*—E. P. Hess, Ohio Injector Co., Wadsworth, Ohio.

Discussion of Examples of Problem Castings.

### STEEL CASTINGS ROUND TABLE LUNCHEON

*Wednesday, October 24, 12:30 P.M.*

*Chairman*—A. H. Jameson, Malleable Iron Fittings Co., Branford, Conn.

Discussion of Committee Reports.

Report of Committee on Specifications for Steel Castings.

Report of Committee on Classification of Alloy and Carbon Steels for Castings.

Report of A.F.A. Representative on Joint Committee on Investigation of Effect of Phosphorus and Sulphur in Steel.

### REFRACTORIES

*Wednesday, October 24, 2:30 P.M.*

*Chairman*—A. V. Leun, Bethlehem Steel Co., Bethlehem, Pa.

*Modern Crucible Melting Equipment*, R. H. Stone, Vesuvius Crucible Co., Swissvale, Pa.

*Refractories for Electric Furnaces Producing Special Irons*, L. C. Hewitt, Laclede-Christy Clay Products Co., St. Louis. In the absence of the author, this paper was presented by J. A. Kayser of the author's firm.

*Properties of Clays from Different Sources*, J. B. Blewett, McLain Fire Brick Co., Wellsville, Ohio.

### PATTERN MAKING

*Wednesday, October 24, 2:30 P.M.*

*Chairman*—Paul Bilhuber, Steinway and Sons, Long Island, N. Y.

Joint Session with Wood Industries Division, American Society of Mechanical Engineers

*Modern Pattern Making Practice*, Vaughan Reid, City Pattern Works, Detroit, Mich.

### GRAY IRON SHOP OPERATION COURSE (Session 3)

*Wednesday, October 24, 4:00 P.M.*

*Chairman*—J. Grennan, University of Michigan, Ann Arbor, Mich.

Small Cupolas and Their Operation. *Discussion Leader*—D. J. Reese, Whiting Corp., Harvey, Ill.

### ANNUAL BANQUET

*Wednesday, October 24, 7:00 P.M.*

President Frank J. Lanahan presiding.

Representatives of the foreign foundry associations were introduced by Vice President D. M. Avey, Chairman of the Committee on International Relations.

The J. H. Whiting Gold Medal of the A.F.A. was presented to Dr. Arnold Lenz, Assistant Manufacturing Manager, Chevrolet Motor Co., Flint, Mich., by Past President T. S. Hammond, Chairman of the Board of Awards.

Andrew W. Robertson, Chairman of the Board of the Westinghouse Electric and Manufacturing Company, Pittsburgh, gave the banquet address, the subject being "Planned Economy."

(Complete details of the banquet proceedings, together with Mr. Robertson's address, may be found in TRANSACTIONS, vol. 5, no. 5, Oct. 1934.)

### SAND CONTROL SHOP OPERATION COURSE (Session 4)

*Thursday, October 25, 9:00 A.M.*

*Chairman*—A. C. Jones, Lebanon Steel Foundry, Lebanon, Pa.

Core Sands and Binders. *Discussion Leader*—J. N. Ludwig, Electro Metallurgical Co., New York.

### CAST IRON FOUNDING

*Thursday, October 25, 10:00 A.M.*

*Chairman*—B. H. Johnson, R. D. Wood Company, Philadelphia

*Cupola High Test Cast Iron*, R. P. Lemoine, Paris, France. (Exchange paper, French Foundry Association.) In the absence of the author this paper was presented by R. S. MacPherran, Allis Chalmers Mfg. Co., Milwaukee, Wis.

*Investigation of Composition of Common Cast Iron for Boilers*, G. Sirovich and G. Vanzetti, Milan, Italy. (Exchange Paper, Italian Foundry Association.)

*Heat Treatment of Cast Iron Cylinder Liners*, W. Paul Eddy, Jr., General Motors Truck Corp., Pontiac, Mich.

*Polishing Cast Iron for Microscopic Examination*, M. F. Surls, Michigan State College, East Lansing, Mich.

### MALLEABLE IRON FOUNDING

*Thursday, October 25, 10:00 A.M.*

*Chairman*—J. H. Lansing, Grand Rapids Malleable Works, Grand Rapids, Mich.

*Metallography of Ferrite in Malleable Cast Iron*, H. A. Schwartz and C. H. Junge, National Malleable & Steel Castings Co., Cleveland. Presented by Dr. Schwartz.

*Effects of Copper in Malleable Cast Iron*, C. H. Lorig, Battelle Memorial Institute, Columbus, Ohio, and C. S. Smith, American Brass Co., Waterbury, Conn. Presented by Mr. Lorig.

*Remarks Covering the Cause for the Incompatibility Occasionally Found Between Tensile Strength and Elongation of Malleable Iron Test Bars*, E. Touceda, Malleable Iron Research Institute, Albany, N. Y.

*Report of Committee on Nomenclature*, Presented by Committee Chairman W. R. Bean, Whiting Corp., Harvey, Ill.

### STEEL FOUNDING

*Thursday, October 25, 10:00 A.M.*

*Chairman*—John Howe Hall, Taylor Wharton Iron & Steel Co., High Bridge, N. J.

*Vice Chairman*—George Batty, Steel Castings Development Bureau, Philadelphia.

*Some Aspects of the Physical Properties of Steel Making*, P. Herasymenko and E. Valenta, Skoda Works Research Institute, Pilsen, Czechoslovakia. (Exchange Paper, Czechoslovakian Foundry Association.) In the absence of the authors, this paper was presented in abstract form by C. E .Sims, American Steel Foundries, East Chicago, Ind.

*Steel Castings*, W. H. Hatfield, Brown-Firth Research Laboratories, Sheffield, England. (Exchange Paper, Institute of British Foundrymen.) In the absence of the author this paper was presented by H. Spence Thomas, Vice President, British Iron and Steel Institute.

### MALLEABLE CAST IRON ROUND TABLE LUNCHEON

*Thursday, October 25, 12:15 P. M.*

*Chairman*—E. E. Griest, Chicago Railway Equipment Co., Chicago.

*Vice Chairman*—F. J. Eppelle, Trenton Malleable Iron Co., Trenton, N. J.

Discussion of Experiences with the Malleable Industry Code.

### CAST IRON ROUND TABLE LUNCHEON

*Thursday, October 25, 12:15 P. M.*

*Chairman*—E. R. Young, Climax Molybdenum Co., Chicago.

Trends in New Developments in Melting.

### ANNUAL BUSINESS MEETING

*Thursday, October 25, 3:00 P. M.*

Report of the Annual Business Meeting will be found on page xiv.

Preceding the business meeting, the membership was addressed by Dr. Arnold Lenz, on the subject of "Foundry Progress." Dr. Lenz's address was reproduced in TRANSACTIONS, vol. 5, no. 5, Oct. 1934, pp. 42-58.

### GRAY IRON SHOP OPERATION COURSE (Session 4)

*Thursday, October 25, 4:30 P. M.*

*Chairman*—Fred J. Walls, Eaton-Erb Foundry Co., Detroit.

Electric Furnace Melting. *Discussion Leader*—R. W. McElwee, Ecorse Foundry Co., Ecorse, Mich.

### SAND CONTROL AND RESEARCH

*Friday, October 26, 9:00 A. M.*

*Chairman*—W. G. Reichert, Singer Mfg. Co., Elizabethport, N. J.

*Analysis of Sea Coal as Applied to Black Sand*, R. E. Aptekar, Ypsilanti, Mich.

*Flowability of Molding Sand*, H. W. Dietert and F. Valtier, Harry W. Dietert Co., Detroit. Presented by Mr. Dietert.

*Comparison of Some Wet Methods Used in Determining the Fineness of Sands*, R. C. Hills, Cornell University, Ithaca, N. Y. In the absence of the author this paper was presented by Dr. H. Ries.

### TESTING CAST IRON — JOINT A.F.A. AND AMERICAN SOCIETY FOR TESTING MATERIALS MEETING

*Friday, October 26, 9:00 A. M.*

*Chairman*—Dr. Jas. T. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala.

*Testing Cast Iron*, R. S. MacPherran, Allis Chalmers Mfg. Co., Milwaukee.

*Chilling Properties of Cast Iron*, W. H. Spencer, American Cast Iron Pipe Co., Birmingham, Ala.

*Fatigue Tests of High-Strength Cast Irons*, H. F. Moore and J. J. Picco, University of Illinois, Urbana, Ill. Presented by Mr. Picco.

*Horizontally Poured Test Bars*, G. Phillips, Frank Foundries Corp., Moline, Ill.

### MATERIALS HANDLING

*Friday, October 26, 9:00 A. M.*

*Chairman*—E. W. Beach, Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

*Selecting Foundry Equipment as an Investment*, R. J. Heisserman, Link-Belt Co., Philadelphia.

*Foundry Maintenance*, J. Thomson, Continental Roll and Steel Foundry Co., East Chicago, Ind.

# Annual Business Meeting

AMERICAN FOUNDRYMEN'S ASSOCIATION
PHILADELPHIA CONVENTION HALL, OCTOBER 25, 1934

*Presiding:* Frank J. Lanahan, President.

As the first order of business, Executive-Secretary C. E. Hoyt read the report of the Nominating Committee, which was as follows:

"A meeting of the Nominating Committee was held at the Chalfonte Hotel, Atlantic City, Thursday, June 28, 1934, with the following present: Past Presidents N. K. B. Patch and E. H. Ballard, and elected members, A. L. Boegehold, W. C. Hamilton and E. F. Hess. Absent: Past President, T. S. Hammond, and E. E. Griest.

"In accordance with the provisions of the By-laws, the Committee nominates officers and directors as follows:

*For President to serve for one year—*

D. M. Avey, Editor, *The Foundry*, Cleveland, Ohio.

*For Vice President to serve for one year—*

B. H. Johnson, Assistant to President, R. D. Wood Company, Philadelphia, Pa.

*For Directors to serve terms of three years each—*

RETIRING PRESIDENT FRANK J. LANAHAN.
E. W. CAMPION, General Manager, Bonney-Floyd Co., Columbus, Ohio.
E. O. BEARDSLEY, President, Beardsley and Piper Co., Chicago.
A. E. HARRISON, General Superintendent of Foundries and Pattern Shop, Allis Chalmers Mfg. Co., Milwaukee, Wis.
SAM TOUR, Vice President, Lucius Pitkin, Inc., New York City.

Respectfully Submitted,

N. K. B. PATCH, *Chairman,*
*1934 Nominating Committee.*

Secretary Hoyt then stated: "This report was submitted to the membership by mail in accordance with the provisions of the By-laws and as no other candidates for officers and directors have been nominated as provided for in the By-laws, your Secretary now casts the unanimous ballot of the members for candidates presented by the Nominating Committee."

The Chair declared the above-named candidates elected, they to assume office at the annual meeting of the Board.

President Lanahan then introduced President-elect Avey and Vice President-elect Johnson.

H. B. Hanley, Chairman of the committee to nominate four members of the 1935 Nominating Committee, presented his committee report. The members nominated by this committee were:

GEORGE W. CANNON, Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

JAMES H. LANSING, Grand Rapids Malleable Works, Grand Rapids, Mich.

VAUGHAN REID, City Pattern Works, Detroit.

KEITH WILLIAMS, Pratt and Letchworth Co., Buffalo, N. Y.

On motion made and duly seconded this report was accepted and approved.

Secretary Hoyt was then called upon to present a report on the election of Honorary Life membership. His report was as follows:

"Prior to this year it has been customary to elect the medalist of each year to Life Membership and to elect the retiring president to Honorary Membership. We now have in our By-laws a provision for Honorary Life Membership.

"The By-laws of the Association provide that the election to Honorary Life Membership shall be by a three-fourths vote of the members of the Association present at a regular meeting thereof, voting on a recommendation of the Directors that the Honorary Life Membership be conferred. At a meeting of the Board of Directors held December 9, 1933, a resolution was unanimously passed recommending that the following A.F.A. gold medallists be elected to Honorary Life Membership at the next annual meeting of the Association:

JOHN HOWE HALL—Whiting Medallist, 1924.
ENRIQUE TOUCEDA—Penton Madillist, 1924.
E. V. RONCERAY—Whiting Medallist, 1926.
JOHN SHAW—Penton Medallist, 1926.
HARRY A. SCHWARTZ—Penton Medallist, 1930.
H. W. GILLETT—McFadden Medallist, 1932.

"All the other medallists are, by virtue of being past presidents, or in the case of Professor Turner, the first honorary member elected to the Association, now Honorary Life Members."

Past President R. A. Bull moved that the report of the Board of Directors be accepted. The motion was seconded and unanimously adopted.

Secretary Hoyt then presented a further recommendation of the Board as follows:

"It is also the Secretary's privilege to report that at a special meeting of the Board of Directors held Monday, October 22, 1934, a resolution was adopted recommending to Honorary Life Membership, Dr. Arnold Lenz, 1934 A.F.A. Gold Medalist."

Past President S. W. Utley moved that the recommendation be accepted and Dr. Lenz be elected an Honorary Life Member. This motion was seconded and unanimously adopted.

Vice President Avey at this time assumed the Chair.

Secretary Hoyt reported that at the special meeting of the Board of Directors held October 22, 1934, a resolution was unanimously adopted that President Frank J. Lanahan be made an Honorary Life Member in accordance with the provisions of the By-laws on the day he retires as President of the Association.

Past President R. A. Bull moved that the resolution be approved. Past President Erb seconded the motion, which was unanimously adopted.

President Lanahan at this point reassumed the Chair, following which Executive Secretary Hoyt made the following remarks:

"The Annual Reports of the Executive Secretary, Treasurer and the Technical Secretary are presented at the annual meetings of the Board of Directors and then to the members in the Printed Transactions.

"We desire, however, a moment of your time in which to sum up the events of this unusually busy week. We will not attempt statistics or comparative figures for this and previous years, for we are

quite content to allow this Convention and the Exhibits to speak for themselves. They are the result of the co-operated efforts of many individuals and groups and we take this opportunity of expressing our sincere appreciation of the contributions of all authors of papers and of reports and we want especially to express appreciation of the splendid co-operation of all during the weeks last summer when our Technical Secretary was ill. Without that co-operation our task would have been a difficult one indeed, and we thank you one and all.

"On page 14 of the Program will be found an Appreciation of Exhibitors, which reads as follows:

> " 'The American Foundrymen's Association takes this opportunity to express to the Exhibitors co-operating in this Exposition, the sincere appreciation of the industry.
>
> " 'The exhibiting companies are engaged in constant research to make the foundry more productive and more efficient. They bring the newest in equipment and materials to the attention of the foundryman and help the progressive man keep up to date. In bad years as in good, they co-operate with this Association, and to a large extent contribute to the success of these annual conventions. To our Exhibitors!'

"That was written before you or I had an opportunity of viewing their splendid efforts made at a time and under conditions that required courage, vision and in many instances real sacrifices. We hope you members will go out of your way to express your appreciation of their efforts and in the days to come remember them when placing orders for equipment and supplies. Keep your Directory of Exhibits for that particular purpose.

"We hope all Exhibitors will find their participation a good dividend paying investment, just as they have helped us to pay you good dividends on your investment in time and money in attending this Convention.

"Recalling now conversations and correspondence of past months I am prompted to condole with some who did not have the courage or for some other reason were prevented from participating and to express the hope they will be with us at the next exhibit in 1936.

"As year after year we have a succession of unusually capable Presidents, your Secretary finds it exceedingly difficult to find words for expressing appreciation of the interest and helpfulness of the incumbent of that office for the particular year. It is a joy to work with them and this year our cup of joy has been kept full and running over by the encouraging words and always capable assistance of President Frank Lanahan.

"We could speak volumes about the helpfulness at all times in every way of Vice President Dan Avey, but being limited in capacity for expression, I must save something for another year.

"Coming down to the weeks of preparation for events we are celebrating, I desire to express sincere appreciation of the helpfulness and splendid work of the members of the Philadelphia Committees and I am sure all of them will support me in making special mention of Mr. and Mrs. B. H. Johnson, Joint Chairmen of the Reception Committees for members and their ladies."

Secretary Hoyt, then referring to the time and place of the next convention, stated that many invitations had been received from cities to hold the 1935 convention. He moved that these invitations be referred to the Board of Directors for consideration and decision.

The motion, on being seconded, was unanimously adopted.

There being no further business to come before the meeting, President Lanahan declared it adjourned.

# Minutes of Board Meetings

The following pages include information on the minutes of the following meetings of the Board of Directors and the Executive Committee of the Board:

*June 29, 1934*—Meeting of the Executive Committee, held in Philadelphia.

*October 22, 1934*—Special Meeting of the Board of Directors, held during the Philadelphia Convention.

*January 12, 1935*—Final Meeting of the 1933-34 Board of Directors, held in Cleveland.

*January 12, 1935*—First Meeting of the 1934-35 Board of Directors, held in Cleveland.

* * *

## Minutes of Executive Committee Meeting 1933-34 Board of Directors

BELLEVUE STRATFORD HOTEL, PHILADELPHIA, JUNE 29, 1934

This meeting was called on the closing day of the annual convention of the American Society for Testing Materials at Atlantic City, and the day following the meeting of the 1934 A. F. A. Nominating Committee which also met at Atlantic City.

Members present: Pres. Frank J. Lanahan, Vice Pres. Dan M. Avey, James L. Wick, Jr., and C. E. Hoyt. Others present: Past Pres. E. H. Ballard and Past Director B. H. Johnson.

Mr. H. Bornstein, member of the committee, who had taken part in informal conferences of committee members at Atlantic City, and had expressed his views on various projects, was unable to be present. Other members absent: T. S. Hammond and Fred Wolf.

Secretary Hoyt submitted draft of Rules and Regulations for governing 1934 exhibit, cartage contract and furniture contract. On motion duly seconded, all were approved.

It was unanimously voted that admission to convention and exhibit should be by badge; that there be a registration fee of $1.00 for non-members, extra representatives of firm members, and extra representatives of exhibitors, with no registration fee for members of record, or for overseas guests.

At this point the committee adjourned to accompany members of a Philadelphia committee on an inspection of the new Convention Hall, returning by way of Franklin Institute, where a hurried inspection was

made of the facilities and accommodations offered for a formal reception to overseas guests on Tuesday evening of convention week.

Returning to the hotel, the committee again convened. Mr. Avey, Chairman of the International Relations Committee, reported on arrangements for the reception of overseas delegations on their arrival in New York, and Preconvention Tour, including itinerary and arrangements for reception and entertainment in each city. The report and recommendations contained therein were unanimously approved.

*Affiliation of Technical Groups*

Secretary Hoyt reported conferences and exchange of correspondence on the subject of some provision on behalf of the Board of A. F. A. for the affiliation of groups organized to undertake general or specific research programs of technical character for some branch of the casting industry.

On motion duly seconded the Executive Secretary was authorized to prepare a Manual for the Organization and Conduct of Affiliated Technical Groups of A. F. A., to be submitted to the members of the Board of Directors for their consideration and possible approval.

Following a report by Secretary Hoyt on the status of the Cast Metals Handbook, and a discussion by those present of the policies of the A. F. A. and other associations regarding defraying travelling expenses of committee members on which no action was taken, the meeting adjourned for dinner.

The following were the guests of the committee at dinner, which was followed by a conference on convention program generally: Walter Yost, Pres., and Earl Sparks, Secretary, Philadelphia Foundrymen's Association, B. H. Johnson, General Chairman, Reception Committee, W. B. Coleman, Plant Visitation Committee, H. L. Henszey, Chairman, Transportation Committee, and Frank Devine, Chairman, Hotel Committee.

Following this conference, the members of the Executive Committee again convened for further discussion of Association policies and activities, including consideration of a communication from Past President A. B. Root, Jr., on the subject of a nation wide survey of the dust hazard in industry, to which the executive secretary was instructed to make reply.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

# Minutes of Special Meeting 1933-34 Board of Directors

BELLEVUE-STRATFORD HOTEL, PHILADELPHIA, OCTOBER 22, 1934

At this special meeting of the Board of Directors which convened just prior to the annual Alumni Dinner, and presided over by Frank J. Lanahan, President, the following Directors were present: D. M. Avey, E. H. Ballard, H. Bornstein, George Batty, R. F. Harrington, R. J. Teetor, James L. Wick, A. G. Storie, W. D. Moore, H. Ries, and Executive Secretary C. E. Hoyt.

On motion of Mr. Moore, seconded by Mr. Ballard, it was unanimously voted to approve the action of the Board of Awards in preparing resolutions of appreciation of the work of John A. Penton, first Secretary and prominent in the organization of the American Foundrymen's Association in Philadelphia, June 18, 1896, and that they further approve of the recommendations of the Board of Awards that a bronze token, a "Baby Pegasus", be presented to John A. Penton as a further appreciation of his outstanding services, and that the funds for defraying the cost of having resolutions engrossed on parchment, and the purchase of the bronze casting be defrayed from funds in the William H. McFadden Award Interest Account.

On motion of Mr. Ballard, seconded by Mr. Avey, it was unanimously voted to recommend to the members of the Association at the annual business meeting to be held Thursday, October 25, that Dr. Arnold Lenz, A. F. A. Medalist for the year 1934 be elected to Honorary Life Membership.

On motion of Mr. Moore, seconded by Mr. Batty, a resolution was unanimously adopted recommending to the members of the American Foundrymen's Association that President Frank J. Lanahan be made an Honorary Life Member of the Association in accordance with the provisions of the By-Laws, on the day of his retirement as President of the Association.

Secretary Hoyt reported that on July 19, 1934, acting in accordance with the recommendations of members of the Executive Committee at a meeting held in Philadelphia, June 29, a manual for the organization and conduct of affiliated technical groups of A. F. A. was submitted to the Directors with the understanding that a ballot approving said manual would not be taken until an opportunity had been given for securing the reaction of Directors and other interested parties.

Secretary Hoyt reported further on conferences and exchange of correspondence that he had had with Past President R. A. Bull, representing a group of technical men of the steel casting industry; that the two of them were in agreement that the manual as originally prepared would not be entirely acceptable for the conduct of such affiliated groups as were proposed; that several redrafts had been made, but unanimous agreement had not been reached on the wording and conditions that should be stipulated in such a manual.

Reporting further, Secretary Hoyt stated that following a meeting of Committee A-3 on Cast Iron of the A. S. T. M. at convention held in

Atlantic City last June, a group of technical men met together to discuss the desirability of organizing a group to be affiliated with the A. F. A. for the purpose of promoting the technical interests of gray iron foundrymen.

Mr. Hoyt then offered the following resolution:

"Be it resolved that the Board of Directors of the American Foundrymen's Association approve in principle, but not necessarily in detail, the draft of a manual for the organization and conduct of affiliated technical groups of the Association which was submitted to the members of the Board by letter, July 19, 1934.

Be it further resolved that the Executive Committee of the Board is hereby authorized to conduct negotiations with groups of individuals representing any branch of the casting industry desirous of becoming affiliated with the Association for the technical advancement of the whole casting industry or any division thereof."

On motion of Mr. Batty, seconded by Mr. Bornstein, resolutions were unanimously approved.

On motion duly seconded, President Lanahan was authorized to appoint a Nominating Committee of three members of A. F. A. to nominate four members of the 1935 Nominating Committee; that they submit a report at the annual meeting of the Association, Thursday, October 25 for the election of four members of the Nominating Committee, in accordance with the provisions of Section 1, Article VIII of the By-Laws.

President Lanahan asked for time to consider, and later named the following as members of this committee: H. B. Handley, American Laundry Machinery Company, H. V. Crawford, General Electric Company, and Lee Wilson, Reading Steel Casting Company.

On motion, meeting stood adjourned, subject to call by the President. Then followed the Alumni Dinner with fifty present including twelve Past Presidents and twelve Old Timers, men who were present at the organization meeting in 1896. Others present were Directors, Past Directors and officers of the Association.

Following the dinner President Lanahan introduced Past President Wells Utley who, on behalf of the Board and members of A. F. A., presented a copy of engrossed resolutions and a bronze token, "Baby Pegasus" to Mr. John A. Penton, first Secretary of the Association.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

# Minutes of Annual Meeting of Board of Directors

CLEVELAND HOTEL, CLEVELAND, JANUARY 12, 1935

This, the final meeting of the 1933-34 Board was scheduled to be held in December, but for various reasons was deferred until this date.

*Roll Call*

In the absence of Pres. Frank J. Lanahan, the meeting was called to order by Vice Pres. D. M. Avey, with the following members present: W. D. Moore, N. K. B. Patch, A. G. Storie, E. H. Ballard, H. Bornstein, George Batty, R. F. Harrington, R. J. Teetor, and J. L. Wick, Jr.

Others present: Vice Pres.-Elect B. H. Johnson, Directors-Elect E. O. Beardsley and Sam Tour; Past Pres. B. D. Fuller, Technical Secretary R. E. Kennedy, Executive Secretary C. E. Hoyt.

Mr. Avey read a letter from President Lanahan expressing regret at not being able to attend this meeting. On motion unanimously carried, the Executive Secretary was instructed to communicate to Pres. Lanahan the regrets of those present that he could not be with them.

On motion by Mr. Ballard, seconded by Mr. Bornstein, it was voted to approve without reading, minutes of the last annual meeting of the Board, held December 9, 1933, which Minutes were printed in Bound Volume of "Transactions" No. 41.

Minutes of meeting of the Executive Committee held at Philadelphia, June 29, 1934, were read by the Secretary, and on motion, approved.

Minutes of special meeting of the Board of Directors, held in Philadelphia, October 22, 1934, were read and approved.

*Executive Secretary's Report*

The Executive Secretary read his annual report to the Board. On motion by Mr. Ballard, seconded by Mr. Patch, report was accepted, ordered filed, and the recommendations for action outlined therein, referred to the incoming Board.

*Treasurer's Report*

The Treasurer read his annual report to the Board. On motion by Mr. Ballard, seconded by Mr. Patch, the report of the Treasurer was accepted and referred to the Finance Committee.

Discussion then followed on the recommendation in the Treasurer's report that the Directors consider some uses for surplus Award Interest funds that would be in keeping with the Articles of Agreement, and recommend to the Board of Awards that appropriations be made from these funds for such purposes.

Director Patch recommended that funds be appropriated for an honorarium for an outstanding lecturer for annual conventions. Director Wick suggested that funds be used for scholarships in certain selected engineering schools. Director-Elect Tour cited the experience of one society in giving scholarships, which practice had been found unsatisfactory, and scholarships had been discontinued. Director Moore proposed

that funds be appropriated for defraying the expense of A. F. A. lecturers appearing before local foundry associations and local sections of A. F. A. This suggestion met with much favor, and it was moved that the Executive Committee be authorized to present the matter to the Board of Awards.

*Report of Technical Secretary*

Technical Secretary R. E. Kennedy had prepared typed copies of his report for each member of the Board, and it was moved that the report be accepted and the discussion of it deferred until the new Board was organized. Motion seconded and carried.

*Report of Manager of Exhibits*

Mr. Hoyt, in submitting his report as Manager of Exhibits, presented statistics and the comparative figures of number of exhibitors and total square feet of space occupied for the ten exhibits held 1925 to 1934 inclusive. Mr. Hoyt stated that when the Board of Directors coupled with the announcement of the 1934 Convention, International Foundry Congress and Exhibit, the announcement that the 1935 convention would be staged without an exhibit, it had been generally accepted as a declaration of a bi-annual exhibit policy, and that on each odd-numbered year a convention would be held without an exhibit, with an exhibit being staged in connection with conventions held on even-numbered years.

Mr. Hoyt stated further that, prompted by the experience with hotel exhibits on three occasions, he would strongly recommend against such limited exhibits of that character on off-years, and that the Association adhere to an every other year exhibit program without restrictions as to operation and space used other than are imposed by limitations of the building occupied. On motion duly seconded, the report of the Manager of Exhibits was accepted and ordered filed.

*Report of International Relations*

Mr. Avey, as Chairman of the Committee on International Relations, reported on the activities of his committee, including all the arrangements for receiving and handling overseas delegations to the International Foundry Congress, the date of their arrival in New York through the Preconvention Tours, the five days of the Congress, and to seeing the various delegations off on their respective boats the day following the Congress.

In the discussion which followed, the value of international relations of industrial groups was stressed, and it was suggested that Chairman Avey submit a summary of the report on overseas delegations at the recent congress, to the Chamber of Commerce of the United States, the United States Department of Commerce, the National Association of Manufacturers' and other groups, citing the commercial advantages of such gatherings.

*Appreciation of Work of the Naval Research Laboratory*

Secretary Hoyt read a communication from Past Pres. Major R. A. Bull, recommending the adoption of resolutions approving work done at the Naval Research Laboratory, of interest to foundrymen, particularly the contributions of Messrs. Briggs and Gezelius, and the papers presented by them at the 1934 A. F. A. convention.

Director Batty reported development of cooperative work at the Naval Research Laboratory on behalf of the steel casting industry. Following discussion, it was moved that a communication and suitable resolutions be submitted to the proper persons and authorities.

*Report of Election of Officers and Directors*

Chairman Avey requested that Past Pres. E. H. Ballard take the Chair, whereupon Secretary Hoyt reported that at the 38th Annual Convention of the Association, held in Philadelphia, Thursday, October 25, the following officers and directors were unanimously elected: Pres. Dan M. Avey, Vice Pres. B. H. Johnson, each to serve term of one year, or until their successors were elected and qualified; Directors Frank J. Lanahan, E. W. Campion, E. O. Beardsley, A. E. Harrison, and Sam Tour, each to serve terms of three years, or until their successors were elected and qualified.

It was moved that the report of election of officers be accepted and filed.

Chairman Ballard then introduced Mr. Avey as the incoming President of the American Foundrymen's Association and presented him with a gavel. Pres. Avey, in accepting the gavel, responded to the introduction and briefly outlined what he hoped to be able to accomplish during his term of office, with the active cooperation of directors and members of the Association.

Mr. Avey then introduced Vice Pres. B. H. Johnson, who, in responding, expressed the pleasure and satisfaction he felt on being returned as an active member of the Board, and expressed appreciation of the honor that had been bestowed on him.

Directors-Elect Sam Tour and E. O. Beardsley were then introduced. Secretary Hoyt read a telegram from Director-Elect E. W. Campion, expressing regret that he was unable to attend the meeting; also a letter of resignation from Director-Elect A. E. Harrison, whose resignation was prompted by his retirement from active business.

Retiring Directors N. K. B. Patch, A. G. Storie and W. D. Moore expressed the pleasure that they had experienced during their terms of office. Secretary Hoyt, speaking for Technical Secretary Kennedy and all the members of the executive staff, expressed appreciation for the support and help of officers and directors during the past year.

On motion of Mr. Ballard, seconded by Mr. Bornstein, the final meeting of the 1933-34 Board of Directors stood adjourned.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

# Minutes of First Meeting 1934-35 Board of Directors

CLEVELAND HOTEL, CLEVELAND, JANUARY 12, 1935

President Avey presided.

This meeting followed adjournment of final meeting of the 1933-34 Board, at which time newly elected officers were installed.

Present: D. M. Avey, President, B. H. Johnson, Vice President, Directors E. H. Ballard, H. Bornstein, George Batty, R. F. Harrington, R. J. Teetor, James L. Wick, Jr., E. O. Beardsley and Sam Tour; Executive Secretary C. E. Hoyt, Technical Secretary R. E. Kennedy, Past Directors N. K. B. Patch, A. G. Storie, S. C. Vessy, and Past President B. D. Fuller.

President Avey announced that the Board would proceed to organize in accordance with the provisions of the By-Laws and that he would appoint Directors E. H. Ballard, George Batty and E. O. Beardsley as a committee to nominate an Executive Secretary, a Treasurer, a Technical Secretary, an Assistant Secretary, a Manager of Exhibits, and four Directors to serve with the President, Vice President, and Executive Secretary as members of the Executive Committee of the Board.

The committee also was instructed to nominate a Director to fill the vacancy caused by the resignation of Mr. A. E. Harrison, whose letter of resignation was presented at the meeting of the retiring Board and referred to the present Board.

The meeting then adjourned for luncheon with the following guests present: Robert Belt, Secretary, Malleable Iron Research Institute; Arthur Tuscany, Secretary, Gray Iron Founders' Society; Herman Lind, Managing Director, National Machine Tool Builders' Association; John Wise, Secretary, Foundry Equipment Manufacturers' Association; Frank Steinebach, Managing Editor, "The Foundry"; and Walter Seelbach, Past President, Gray Iron Institute.

Following luncheon the meeting reconvened and the Chair called for the report of the Nominating Committee, which was presented by E. H. Ballard, Chairman, who reported as follows:

> "The committee recommends that following the usual custom and in accordance with the provisions of Section 1, Article IV of the By-Laws, that the offices of Executive Secretary, Treasurer, and Manager of Exhibits be combined, and the chairman so moves."
> (*Motion seconded and unanimously carried.*)
>
> Continuing his report, Mr. Ballard said, "For the combined office of Executive Secretary, Treasurer, and Manager of Exhibits, we nominate C. E. Hoyt.
> "For the office of Technical Secretary we nominate R. E. Kennedy.
> "For the office of Assistant Secretary-Treasurer we nominate Miss Jennie Reininga."

On motion duly seconded, the nominees for each office were balloted on separately and duly elected.

Mr. Ballard, continuing, said the committee nominated Directors

Frank J. Lanahan, H. Bornstein, James L. Wick, Jr. and Ralph J. Teetor to serve with the President, Vice President and Executive Secretary as members of the Executive Committee. On motion duly seconded, the above named Directors were elected as members of the Executive Committee of the Board.

Mr. Ballard then placed in nomination on behalf of the committee, the name of Walter Seelbach of Forest City Foundries, Cleveland, as a Director to fill the unexpired term of A. E. Harrison, resigned. On motion duly seconded, Mr. Seelbach was elected a Director of the Association, and the Secretary was requested to acquaint Mr. Seelbach with his election and invite him to the Board Meeting.

President Avey called for the report of the Finance Committee. In the absence of Chairman Lanahan, the report was presented by Mr. Ballard. Mr. Ballard reported that during the recess, the Finance Committee had examined the Finance Report of the Treasurer presented at the previous Board Meeting and compared it with the report of the Auditor, Robert T. Pritchard; that they had also examined the summary of the Auditor's Report which had been prepared by Edwin W. Wright, of Pittsburgh, personal auditor of Chairman Lanahan, and that they had found all these reports substantially in accord, and recommended their acceptance and approval. On motion duly seconded, the report of the Finance Committee and of the Auditor, Robert T. Pritchard, were accepted and ordered filed.

President Avey then called for a report and recommendations of the Finance Committee on salaries for the ensuing year, and Chairman Ballard continuing, said:

> "Your committee makes the following recommendations on salaries for the period beginning January 1, 1935:
> "Salary, Executive Secretary-Treasurer, $320.00 per month.
> "Salary, Technical Secretary, $450.00 per month.
> "Salary, Manager of Exhibits, $320.00 per month.
> "Salary, Assistant Secretary-Treasurer, $192.00 per month.
> "We further recommend that the President and Executive Secretary be authorized to employ such office assistants as are necessary for the conduct of Association business, and determine compensation."

On motion duly seconded, the recommendations of the Finance Committee on salaries and compensations were approved.

Mr. Ballard continuing, commented upon the services and salary of R. E. Kennedy, Technical Secretary, stating that in the light of action taken at the last annual Board Meeting on salary, it was the recommendation of the Finance Committee that Mr. Kennedy be given a bonus of $150.00 for the period ending December 31, 1934. On motion duly seconded, Mr. Kennedy was voted a bonus of $150.00.

On motion duly seconded, the bonds of C. E. Hoyt, Executive Secretary-Treasurer, and Jennie Reininga, Assistant, were placed at $5,000 each, premium to be paid by the Association.

On motion duly seconded, the following resolutions on disbursement of funds were unanimously adopted:

> "Resolved that resolutions required by the Harris Trust and Savings Bank, Chicago, authorizing withdrawal of funds, are hereby approved, and the Executive Secretary authorized to certify thereto.

"Resolved that checks for the withdrawal of funds deposited in the name of the Association, and the withdrawal of all securities in the Sinking Fund in the Department of Exhibits of the American Foundrymen's Association, held by the Trust Department of the Harris Trust and Savings Bank, and the withdrawal of all funds in all interest savings accounts of the Association shall require two signatures, as follows: The President and Executive Secretary-Treasurer, the Vice President and the Executive Secretary-Treasurer, or the President and the Vice President.

"Be it further resolved that the Board of Directors authorize an Executive Secretary Expense Account of $500.00, said account to be reconciled at the end of each month by a full statement of expenditures, withdrawal checks to be signed by the Executive Secretary-Treasurer or the Assistant Secretary-Treasurer."

On motion duly seconded it was voted to continue in effect the resolution adopted at the last annual meeting authorizing payment of committee meeting expenses, which read as follows:

"Resolved that the Treasurer be authorized to reimburse the traveling expenses of Directors and committee members for attendance at any regularly called Board or committee meeting, with the following exceptions: when meetings are held in conjunction with other committees or associations, the Treasurer is authorized to determine what portion of the expense of attending such meetings shall be paid by the Association.

"No expenses shall be paid to Directors for attendance at meetings held during the week of the annual convention of the Association unless specifically authorized."

Secretary Hoyt commented on the responsibility these resolutions placed on him in the matter of determining the apportioning of expense of committee members in attending meetings held jointly with other associations and societies. Following discussion it was moved, seconded and carried that in a case of such expenses, or when called upon to authorize expenses of the committee members being defrayed, he should ask for the approval of the Executive Committee.

It was duly moved, seconded and carried that the President be authorized to make all appointments for standing or special committees not provided for in the By-Laws or by special act of the Board.

At this time, newly elected Director Walter Seelbach appeared. He was introduced to the members by President Avey, and responded, saying he felt it was one of the highest honors that could be bestowed on a foundryman to be elected to the Board of Directors of A.F.A. and that he would consider it a privilege and pleasure to serve as a member of this Board.

President Avey announced that the next order of business would be consideration of report of the Technical Secretary submitted in typed form at the meeting of the old Board and referred to the new Board for action. The subjects were presented by Secretary Kennedy in the order in which they appeared in his report.

*Joint Meetings with Engineering Societies and Engineering Schools.*

Following discussion the Board voted to approve the holding of such meetings and that expenditures which might be incurred on behalf of the A.F.A. in promoting such meetings should be approved by the Executive Committee.

*Steel Division Organization.*

The recommendation of the Advisory Committee of the Steel Division that divisional organizations be changed, was considered. This recommendation was approved and it was voted to request the Steel Division to submit a set of regulations for Board approval. This action was further amplified by the recommendation that the divisional activities correlation committee should study division set-ups and bring in recommendations as to how all the divisions should be organized.

*Data on Nonferrous Cast Alloys.*

On motion duly seconded, it was voted that a request be forwarded to the Bureau of Standards that they co-operate in obtaining data on properties of cast metals which are shown to be lacking in the nonferrous section of the Cast Metals Handbook.

*Continuation of Cost Committee.*

Director Wick, who has served as chairman of this committee for the past few years, raised the question as to the desirability of dropping this activity. Director Tour and others voiced the opinion that the Cost Committee should be maintained as there were possibilities of activities of value to the Association which could be carried on. Mr. Tour emphasized the fact that a worthwhile activity would be the correlation of the various cost systems of the branches of the industry, and felt that a committee consisting of representatives of each of the foundry Code Authorities could reconcile differences in the various foundry cost systems. On motion the Board voted to approve such a program.

*Foundry Sand Research.*

Following discussion of possible activities of the foundry sand research committee, the Board voted to approve of special funds being raised, provided Director Ries, the Chairman of the committee, submitted a plan of activities that would require funds, and of sufficient importance to justify these being raised.

*Local Sections A.F.A.*

Following discussion, Mr. Bornstein moved that the Board go on record as favoring active work in the promotion of local sections. The motion was approved. Discussion followed as to the advantage of having some lecturer appear before local sections and local associations, and on motion the Board voted to approve such a program, and recommended that consideration be given to defraying expenses of special lecturer from Awards Fund.

*Handbook on Cast Metals.*

The Technical Secretary reported that as a result of the work of committees on the Cast Metals Handbook, the material for each Division, cast iron, steel, malleable and nonferrous, was practically complete and

we could look forward to publication of this work during the summer of 1935.

Following discussion of this activity, which was inaugurated by a joint committee sponsored by the A.F.A. and which had later, of necessity, become a definite responsibility of the A.F.A., it was moved that the work of all committees and sub-committees should be accepted with appreciation for the work of the members thereof, and that all be relieved of further responsibility in the printing and publishing of this work.

It was further moved that a committee consisting of one individual from each of the four divisions of the casting industry, and a representative of A.F.A. Joint Committee on Foundry Education in Engineering Schools, which committee had initiated the work of producing a Cast Metals Handbook, be appointed to co-operate with the Executive Secretary and the Technical Secretary in determining policies to be followed in producing the Handbook, the selection of printers or publishers, methods of making copies available to members, prices to be charged to non-member foundries and methods to be employed in making copies available to engineering schools, to designers and purchasers of castings, and recommendations to be submitted to the Executive Committee of the A.F.A. for approval.

The above motions were duly seconded and carried.

*Simplification of Cupola Refractories.*

On motion the Board voted to approve the recommendations of the Division of Simplified Practices of the Bureau of Standards on Simplification of Cupola Refractories, and that the Bureau of Standards be notified of this action.

*Annual Convention.*

Secretary Hoyt, in submitting a report of invitations for holding the 1935 annual convention of the Association, recommended that the Board first consider the time of year for holding the 1936 convention and exhibit. On motion duly seconded, it was voted to return to the practice of holding May conventions in the year 1936.

Secretary Hoyt then suggested that the period of approximately twenty months from October, 1934 to May, 1936, be divided into approximately equal periods in determining the time of staging the 1935 convention. Acting upon this recommendation it was duly voted to hold the 1935 convention during the month of August.

It was then moved, seconded and carried that the Executive Committee be authorized to consider the invitations extended for holding conventions, and submit their recommendations to the Board of Directors for letter ballot as to the place and date of both the 1935 and 1936 conventions.

Secretary Hoyt reported that the Philadelphia Research Fund, which was, by act of the Board in 1932, made available for defraying expenses of Handbook preparation, had been practically exhausted, and recommended that this account be closed out and balance credited to Cast

Metals Handbook expense. On motion duly seconded and carried, the closing of this account was authorized.

On motion duly seconded, the following resolution was adopted:

"Resolved that the Executive Committee of this Board be empowered to act for the Board in the interim between Board meetings on all matters requiring Board action."

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

# Auditor's Report

August 25, 1934

Mr. Frank J. Lanahan, President,
American Foundrymen's Association, Inc.,
Chicago, Ill.

Dear Sir:

I have examined the books of the American Foundrymen's Association, Inc., for the year ending June 30, 1934, and submit herewith the following statements:

Exhibit A—Balance Sheet, June 30, 1934
Exhibit B—Income and Expenses for the Year
Exhibit C—Surplus, June 30, 1934
Schedule I—Award Funds, June 30, 1934
Schedule II—Reserve Fund, June 30, 1934
Schedule III—Cash Receipts and Disbursements

The securities in the reserve fund as shown by the Balance Sheet are stated at cost and no adjustment has been made for shrinkage in their market value.

Accounts receivable include $921.75 for dues of members for the past year and which are of doubtful value.

There is an excess of Expense over Receipts for the year of $10,105.84 which was partly offset by appropriations out of the Reserve Fund of $6,856.74. It should be noted, however, that the Statement of Income and Expenses, Exhibit B, does not take into consideration any receipts on account of the Exhibit and Convention which were postponed from May to October 1934, although expenses include part of the cost incurred in anticipation of these events.

Subject to these remarks, it is my opinion that the Balance Sheet as at June 30, 1934, shown in Exhibit A attached, correctly reflects the condition of the Association at that date and as shown by the books.

Respectfully submitted,

ROBERT T. PRITCHARD,
*Certified Public Accountant.*

Note: A copy of the Auditor's Balance Sheet and Statement of Cash Receipts and Disbursements is shown in the following pages.

## BALANCE SHEET AS AT JUNE 30, 1934

### ASSETS

| | June 30, 1934 |
|---|---|
| ASSOCIATION ASSETS— | |
| Cash in Bank, Schedule III | $ 1,005.28 |
| Accounts Receivable | |
| Dues | 921.75 |
| Supplies on Hand | 1,094.13 |
| Prepaid Expense on Account of Exhibits | 895.22 |
| Due by Awards Fund | 11.63 |
| Furniture and Fixtures, less Depreciation Reserve | 340.40 |
| | 4,268.41 |
| RESERVE FUND (Schedule II) | |
| Investments (Market Value—$20,288.75) | 21,705.55 |
| Cash in Bank on Savings Account | 7.53 |
| | 21,713.06 |
| PHILADELPHIA RESEARCH FUND | |
| Cash in Bank on Savings Account | 310.15 |
| STEEL CASTINGS TEST FUND | |
| Cash in Bank on Savings Account | 306.43 |
| Total | $26,598.07 |

### LIABILITIES

| | June 30, 1934 |
|---|---|
| ASSOCIATION LIABILITIES | |
| Unpaid Bills | $ 2,086.53 |
| Note to Bank due July 5, 1934 | 1,000.00 |
| Dues Paid in Advance | 185.25 |
| Exhibitors Rental, etc., Paid in Advance | 1,125.00 |
| Unexpended Appropriations for Research | |
| Sand | 351.76 |
| Steel Castings Surfaces | 1,350.00 |
| Phosphorus and Sulphur in Steel | 100.00 |
| | 6,198.54 |
| Surplus (Deficit) | 1,930.13 |
| | 4,268.41 |
| RESERVE FUND (Schedule II) | |
| Principal of the Fund | 21,713.08 |
| PHILADELPHIA RESEARCH FUND | |
| Balance of Subscription | 310.15 |
| STEEL CASTINGS TEST FUND | |
| Unexpended Appropriation | 306.43 |
| Total | $26,598.07 |

## CASH RECEIPTS AND DISBURSEMENTS

For the Year Ending June 30, 1934

| | | |
|---|---|---|
| CASH IN BANK, July 1, 1933 | | $ 1,317.04 |
| RECEIPTS | | |
| Dues and Subscriptions | $20,549.26 | |
| Century of Progress Tickets | 728.50 | |
| Accounts Receivable at July 1, 1933 Collected | 1,895.86 | |
| Loan—Harris Trust and Savings Bank | 1,000.00 | |
| Appropriated from Reserve Fund | 6,856.74 | |
| Exhibitors Permits | 925.00 | |
| Space Rental | 25.00 | |
| Philadelphia Research Fund for Account of Handbook | 815.79 | |
| Total Receipts | | 32,796.15 |
| | | $34,113.19 |
| DISBURSEMENTS | | |
| Salaries, Clerical and Stenography | $18,185.88 | |
| Committee Travelling Expense | 1,569.13 | |
| Publications | 6,337.83 | |
| Printing | 1,617.57 | |
| Postage | 1,468.38 | |
| Office Rent | 1,620.00 | |
| Telephone and Telegraph | 348.09 | |
| Office Expense | 408.32 | |
| Exchange and Tax on Checks | 93.85 | |
| General Expense | 74.25 | |
| Travelling Expense | 450.67 | |
| Insurance | 25.00 | |
| Dues of Other Associations | 73.50 | |
| Audit | 150.00 | |
| District Association Expense | 291.39 | |
| Interest Paid | 4.31 | |
| Personal Property Tax | 42.91 | |
| Furniture Bought | 105.50 | |
| Convention Expense | 10.59 | |
| Awards Fund—Expense Item Advanced | 11.63 | |
| Sand Research | 112.11 | |
| Exhibit Installation | 107.00 | |
| Total Disbursements | | 33,107.91 |
| CASH IN BANK, June 30, 1934 | | $ 1,005.28 |

# The Forehearth as Used in Iron Foundry Practice

By George S. Evans,* New York City

**Abstract**

*This paper gives a survey of the use of the forehearth in modern iron foundry practice. The author takes up the different types of forehearths, describing and illustrating each one. He points out the especial advantages of each type, and cites examples of their efficient operation. Some factors which are given as objections to the use of forehearths are discussed, and methods of practice which will overcome these effects are given. The author emphasizes the importance of selecting the right kind of forehearth for the job, taking into consideration the kind of casting made, the tonnage melted, etc. He discusses the benefits derived from proper use of the forehearth, and pictures typical installations.*

1. In one sense a forehearth may be considered as the hearth of the cupola furnace, offset for receiving the metal from the cupola as melted and to better serve as a mixing and storage reservoir.

2. Forehearths have been in fairly general use in Continental European foundry practice for a great many years. Although occasional installations were reported in American foundries in the past, active interest in this type of equipment dates from the development of a practical process of desulphurizing cupola metal some ten or more years ago. However, desulphurizing is only one of several advantages offered by this process of cupola operation.

3. In ordinary cupola practice the hearth of the cupola is expected to serve both as a storage and mixing reservoir. However, thorough mixing is prevented by the effect of the bed coke in retarding free movement of the metal in the hearth. In fact, there is a tendency for the molten iron to build up in the hearth in

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Note: This paper was presented at one of the Gray Iron Shop Course meetings at the 1934 Convention of the A.F.A.

layers. To insure proper mixture of the different components of the metal charge, it is customary in foundries making specification work to have each tap equal one or more cupola charges.

4. Also, in ordinary cupola practice, with intermittent tapping of metal and slag, more or less of the bed coke is blocked off

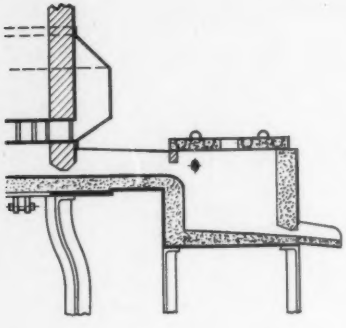


FIG. 1—STANDARD MIXING AND REFINING FOREHEARTH.

from the blast by the overlaying slag and iron. By stopping combustion, this greatly reduces the effectiveness of the bed coke both as a super-heating and deoxidizing agent. Then, as the iron level is lowered in the hearth with the tap, portions of overlaying slag adhere to the surface of the bed coke. This reduces the active surface area of the coke bed and retards complete combustion, *i.e.*, reaction between the oxygen in the blast and carbon of the coke to form carbon dioxide or monoxide gases. The effect is both to prolong the exposure of the metal to oxidation and to limit the reducing action of the bed coke.

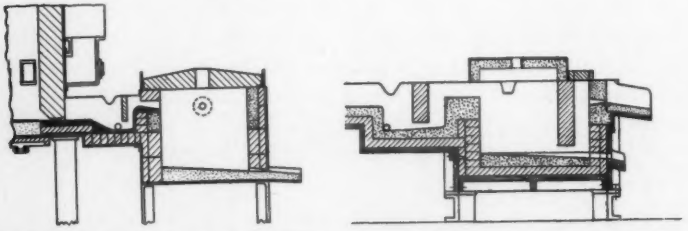


FIG. 2—LEFT—STANDARD FOREHEARTH FOR CONTINUOUS MELTING WITH INTERMITTENT TAPPING. RIGHT—STANDARD FOREHEARTH FOR CONTINUOUS DELIVERY OF IRON AT THE POURING STATION.

5. Forehearth equipment may be divided into three general types depending upon the manner of carrying out the melting operation:

Type 1. Cupola is slagged at the back and the metal tapped into the forehearth at intervals, as in ordinary cupola practice, illustrated by Fig. 1, the forehearth serving simply as a mixing and refining reservoir.

Type 2. Continuous flow of the metal and slag from the cupola and intermittent tapping of the forehearth, shown at the left in Fig. 2. The cupola slag may be made to flow off continuously at the back of the furnace, may be separated from the iron by a slag dam between the cupola and forehearth, or allowed to run into the forehearth with the iron.

Type 3. Continuous flow from the cupola and through the forehearth with separation of slag in the spout and delivery of continuous stream of metal at the pouring station, as shown at the right in Fig. 2.

6. A fourth type of forehearth, shown at the left in Fig. 3, of which one or two are in use in the United States, is built on

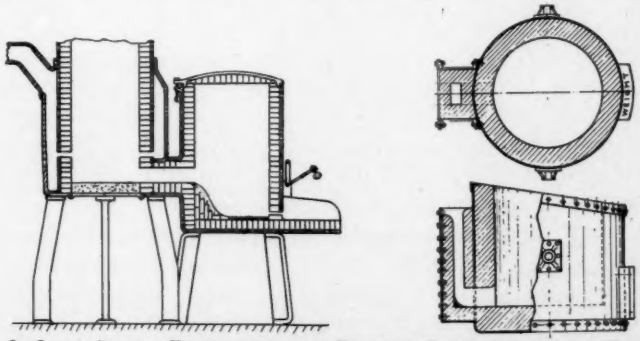


FIG. 3—LEFT—SPECIAL FOREHEARTH WITH ENCLOSED CONNECTION TO THE CUPOLA HEARTH. RIGHT—TEAPOT LADLE BOWL.

to the shell with a direct connection between the cupola hearth and the forehearth. Slag collects in the forehearth with the iron and may be slagged off during the heat or may be allowed to build up and is dumped at the end of the day. Here, the forehearth is tapped at intervals as in ordinary cupola melting.

7. From the standpoint of its operation a teapot ladle, shown at the right in Fig. 3, can be classified as a tilting forehearth.

## ADVANTAGES OF DIFFERENT TYPES

8. The main advantage of Type 1 (where the metal is not to be refined) over the use of an ordinary lip ladle as a mixing reservoir, lies in the fact that the metal is always drawn off the bottom, thus holding back any impurities which may have risen out of the iron while standing in the forehearth. Similar advantages may be ascribed to a teapot ladle. However, if desulphurizing is contemplated, this type offers an opportunity for refining the metal for heavy castings without otherwise affecting the regular operating routine. It is evident from the design and manner of operation of this equipment that it is possible to make almost equally sharp cuts of the iron from different mixtures during a heat as with ordinary practice.

9. Types 2 and 3 provide for continuous flow of the molten iron and slag from the cupola—generally followed with most forehearth installations. As a result, they offer certain other important advantages. For instance, since both iron and slag flow from the cupola as melted, the entire bed zone is maintained in an active condition at all times during the progress of the heat, an important factor in the success of the forehearth process, particularly as applied to the production of light castings.

10. In effect, continuous melting is comparable to increasing the depth of incandescent coke in the superheating zone of the cupola and accounts for the increase in melting temperature generally noticed when changing over from intermittent tapping to this system of melting. Thus, the effectiveness of the bed coke as a deoxidizing agent is doubly increased.

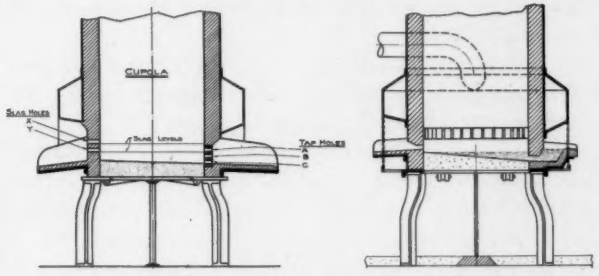
11. Due to the increase in temperature, the rate of absorption of carbon by the molten iron is accelerated. Consequently, the carbon pick-up, when operating with ordinary gray iron mixtures, is sufficient to maintain normal total carbon contents. Although the rate of carbon absorption is faster, nevertheless, with high

steel mixtures, the resultant total carbon usually will be less than with intermittent tapping where the metal is held in the hearth in contact with the coke.

## SLAGGING THE CUPOLA

12. If complete carbon saturation is required or where a definite carbon content somewhat below the saturation point is desired, this may be accomplished with continuous melting by maintaining a fixed pool of metal in the cupola hearth during the melt. Fig. 4 shows two methods of regulating the depth of metal, or both head of metal and slag, held back in the cupola hearth.

13. In type *A*, the iron flows continuously from the upper tap hole, which is made somewhat smaller than required for the




TYPE *A* TYPE *B*

FIG. 4—TWO SYSTEMS OF CONTINUOUS MELTING WITH BACK SLAGGING.

melting rate. The iron gradually rises in the cupola, finally showing at the slag hole, at which time the lower hole is opened for one or two minutes. In type *B*, the tap hole is sealed at all times by the head of iron and can be considerably larger than required for the melting rate. The depth of iron in the hearth may be regulated as required by varying the height of the dam spout.

14. Either tapping system illustrated in Fig. 4 can be used in connection with forehearth or teapot ladle installation where it is advantageous to continue slagging the cupola at the back. With type *A* the cupola can be stopped up over the lunch hour.

## OBJECTIONS TO FOREHEARTHS

15. One objection often raised against the forehearth or teapot ladle process is that it adds one more piece of equipment to be maintained. Another, raised especially by plant managers making light work, is the loss of temperature and its effect upon

fluidity. There is no argument to the first mentioned except to say that the advantages arising from the use of a properly adapted forehearth and refining the metal with fused soda ash, will generally outweigh the original cost of equipment and maintenance charges many times over.

*Loss of Temperature.*

16. There is, of course, always some loss of temperature in the forehearth, especially at the start. Except possibly in the production of the very lightest class of castings, such as small automobile piston rings, this is generally not a serious problem. The regular use of forehearths in the production of such thin sections as radiation, sewing machine and light hardware castings, illustrates that any loss in fluidity can be overcome with correct equipment and proper procedure.

17. The loss is usually greater with Type 1 and may vary from 150 degrees Fahr. at the start to an average of 50 or 75 degrees Fahr. all during the heat. In Types 2 and 3, the surface area of the lining is generally greater for a given mass of iron and with insufficient heating the loss will be great at the start but, with proper design and good practice, should average not more than 25 to 75 degrees Fahr. The drop in temperature will depend, first, upon the extent to which the forehearth has been heated; second, upon the ratio of capacity to melting rate, which regulates the time metal is held; third, ratio of surface area of the lining to mass of metal—more important at the start; and finally, design of lay-out which influences loss by radiation.

*Preheating Forehearth.*

18. In the production of heavy work, heating of the equipment is of secondary importance and the forehearth usually can be warmed-up sufficiently with a portable oil burner or, in some cases, with a wood or coke fire. However, in the production of light work, thorough heating is very important to prevent excessive loss due to absorption of heat units from the first iron by the lining. Provisions for heating the forehearth with either gas or oil should be made a part of the permanent equipment and heating should be continued from 30 minutes to two hours before the first tap, depending upon temperature required. Two arrangements of permanent burner installations are illustrated in Fig. 5. The burners usually are equipped with a pivot joint and are swung

away from the opening with the first cupola tap. In some foundries, the burners are kept going throughout the duration of the heat. From the standpoint of fluidity, this is generally not necessary, but some operators have found that this practice offers some refinement of structure and physical properties of the iron and the cost of the extra fuel is not prohibitive.

*Effect on Fluidity*

19. As explained, an increase in melting temperature with some added deoxidation of the metal, both of which tend to promote fluidity, can be expected with continuous melting. Desulphurizing

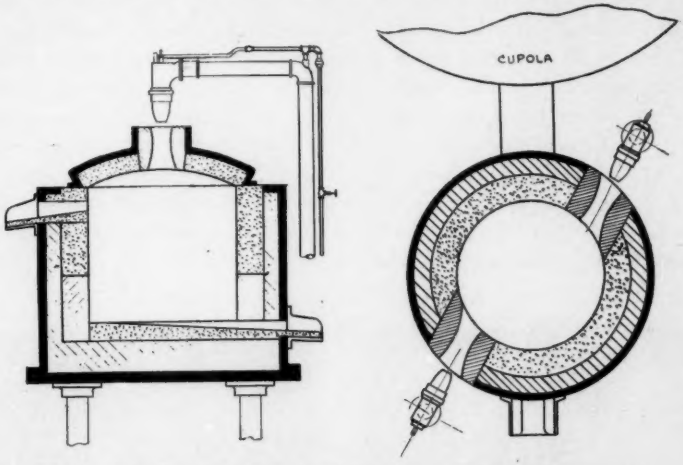



FIG. 5—ARRANGEMENTS USED FOR BURNERS FOR HEATING FOREHEARTH.

to the extent of 20 to 40 per cent of the sulphur present will further promote fluidity. In a properly designed forehearth, the combined effect of higher melting temperature and the refining generally will overbalance any loss in fluidity from temperature drop. In fact, an improvement in sharpness of lines and surface quality in the finished castings is not unusual when the equipment and procedure are properly adapted to the class of work produced. As a means of overcoming loss of temperature at the start, it is customary at most plants equipped with forehearths to favor the first iron by pouring the heavier castings and molds nearest the cupola first.

20. Possibly a word of caution concerning the importance of

selecting the proper equipment and correlating the process in relation to the cupola melting rate and weight of castings produced, may be well at this point. The extent of desulphurizing, for instance, must ordinarily be limited to a value known to be practical for similarly light castings. In the production of chunky work, a reduction of upwards of 50 to 60 per cent sulphur present is thoroughly practical. However, it is impractical to go much beyond 30 or 35 per cent in the production of light work and, in some instances, 15 per cent may prove to be the top limit.

21. The slagging spout forehearth, shown at the left in Fig. 6, with a holding capacity as low as 50 lbs., compared to the 12-ton forehearth, shown at the right in Fig. 6, illustrates proper adaptation of the equipment to the class of operations. The primary object of the slagging spout is to permit continuous melting with separation of the slag and to provide a continuous supply of iron of maximum temperature and fluidity at the spout. The primary object of the 12-ton forehearth, as used in the manufacture of heavy cast iron pipe, is uniform control of temperature and composition. With the smaller installation, it is customary to add the soda ash in the cupola. Here it serves both to improve combustion and to form an active refining slag in the hearth.

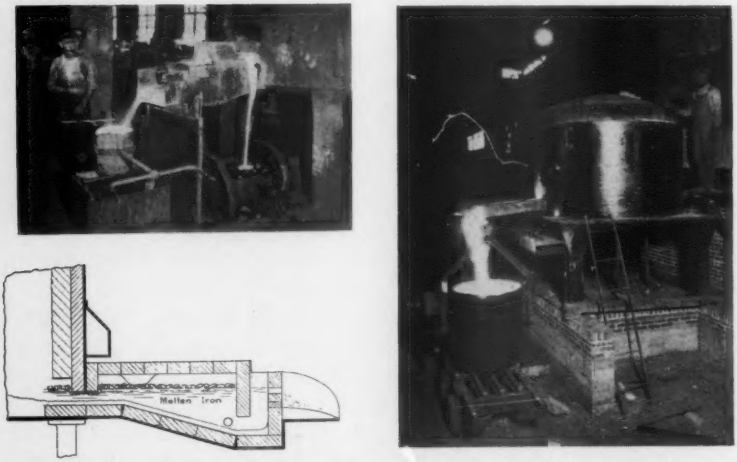



FIG. 6—LEFT ABOVE—SLAGGING SPOUT FOREHEARTH USED TO OBTAIN MAXIMUM TEMPERATURE AND FLUIDITY. LEFT BELOW—SECTIONAL VIEW OF SLAGGING SPOUT FOREHEARTH. RIGHT—12-TON FOREHEARTH USED TO OBTAIN UNIFORM CONTROL OF TEMPERATURE AND COMPOSITION.

## OTHER BENEFITS FROM USE OF FOREHEARTHS

22. Another advantage of the use of forehearths is the tendency towards flattening out variations in temperature and composition of the metal throughout the duration of the heat. For instance, in the operation of a forehearth or teapot ladle, it is customary to carry a good bath of iron in the reservoir all during the heat. With continuous flow into and out of the reservoir, variations in the iron from the cupola are minimized. The bath of iron is kept in continual motion, first through agitation by the stream of metal from the cupola and second, due to heat convection currents, and, in the case of the teapot ladle, by intermittent tilting. This results in a thorough mixing. Another advantage is the

**Table 1**

SHOWING UNIFORMITY OF COMPOSITION OBTAINED IN THREE, CONSECUTIVE, 8-HOUR HEATS

| | Silicon, Per Cent | Manganese, Per Cent | Combined Carbon, Per Cent | Total Carbon, Per Cent | Phosphorus, Per Cent | Sulphur, Per Cent |
|---|---|---|---|---|---|---|
| Cast "A"— | 2.25 | 0.51 | 0.54 | 3.37 | 0.494 | 0.099 |
| "A"— | 2.15 | 0.50 | 0.57 | 3.39 | 0.523 | 0.097 |
| Cast "B"— | 2.24 | 0.50 | 0.59 | 3.32 | 0.515 | 0.097 |
| "B"— | 2.17 | 0.50 | 0.57 | 3.37 | 0.531 | 0.098 |
| "B"— | 2.18 | 0.48 | 0.68 | 3.38 | 0.510 | 0.102 |
| Cast "C"— | 2.21 | 0.48 | 0.54 | 3.34 | 0.512 | 0.098 |
| "C"— | 2.21 | 0.46 | 0.52 | 3.31 | 0.514 | 0.106 |

effect of head pressure in floating slag inclusions to the surface of the bath. Additions of fused soda ash to the bath, as practiced with most such installations, cause a violent boiling action as the reagent melts, beside forming a basic slag for absorbing and holding both sulphur and entrained oxide impurities.

23. The effect of flattening out variations in sulphur contents is particularly noticeable and may be explained by the fact that wherever a soda slag bath is used, this generally is kept sufficiently basic to care for temporary excesses of sulphur. Something of the uniformity of composition that can be expected is illustrated in Table 1, which shows analyses of samples from different parts of three consecutive eight-hour heats operating on a mixture running over 90 per cent scrap. These results were obtained in a radiator foundry using a 5-ton, teapot, reservoir ladle. The melting rate was 15 tons per hour, and 2 pounds of fused soda ash per ton was

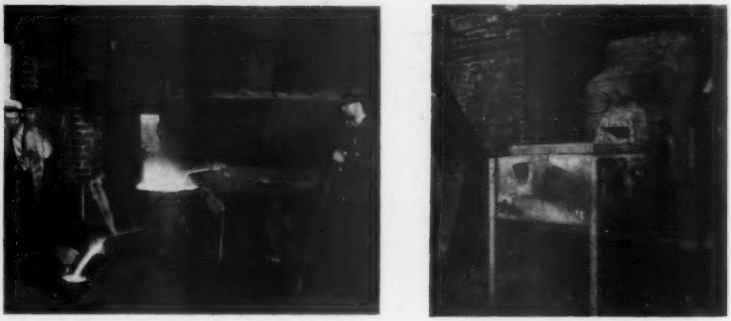


FIG. 7—LEFT—CUPOLA EQUIPPED WITH TUB-TYPE FOREHEARTH. RIGHT—ILLUSTRATION OF A BOX-TYPE FOREHEARTH.

used in the cupola and 6 pounds per ton in the teapot ladle. Sulphur in the metal at the cupola spout varied from about 0.13 to 0.16 per cent.

24. Figs. 1, 2 and 3-Right, illustrate what might be called standard forehearth or teapot ladle equipment. In size, forehearth installations range from the so-called "slagging spout," Fig. 6, Left, with a holding capacity up to 1000 pounds, to the 12-ton forehearth, Fig. 6, Right, or larger. Something of the simplicity of some installations is illustrated by Fig. 7, while Fig. 8 illustrates a rather complicated arrangement in which the metal is tunneled to the far end of the forehearth and flows back to the pouring station ladle. The dam brick in the cupola spout is provided with a tap hole which can be opened at any time, thus cutting out the forehearth and changing the flow of metal direct from the cupola to the pouring station ladle.

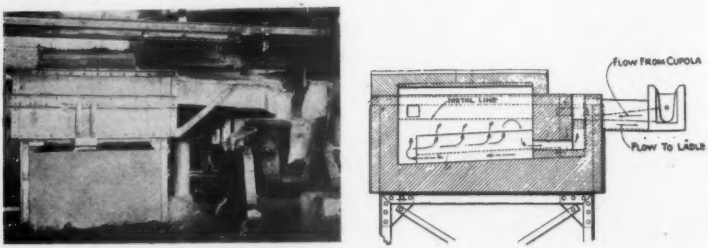



FIG. 8—ELONGATED FOREHEARTH SET AT RIGHT ANGLES TO THE CUPOLA SPOUT. IRON IS TUNNELED TO THE FAR END AND FLOWS BACK THROUGH THE FOREHEARTH CHAMBER TO THE POURING LADLE. LEFT—A TYPICAL INSTALLATION. RIGHT—SECTIONAL VIEW OF ELONGATED FOREHEARTH.

25. A teapot crane ladle, Fig. 9, or truck ladle with teapot spout, is sometimes used for desulphurizing. This process is not unlike the fixed teapot reservoir system. It is thoroughly practical for medium to light section castings provided a good head of iron is carried in the ladle at all times. In operation, the refining agent is added to the first ladle immediately after the iron covers the outlet spout. Desulphurizing takes place while the ladle is being filled and transported to the pouring floor. Approximately two-thirds, never more than three-fourths, of the iron in the ladle is poured. The remaining iron is carried back to the cupola, where

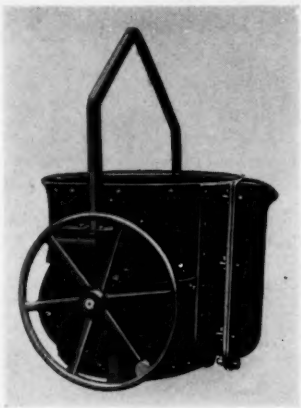


FIG. 9—TEAPOT-TYPE CRANE LADLE WHICH IS SOMETIMES USED FOR DESULPHURIZING.

additional refining agent is added and the ladle re-filled. That practice is carried on throughout the duration of the heat.

26. This process is not generally recommended except with ladle capacities of 2000 lbs. or over and where it is practical to hold back a minimum of 500 or 700 lbs. of iron in the ladle after each pour. If smaller ladles are used, relatively more iron should be carried back in the ladle and in no case should this system be attempted with ladles of less than 1000 lbs. actual working capacity.

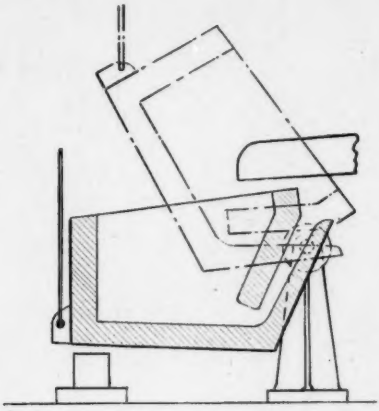
27. The ladle generally is equipped with a marker to insure against pouring too much metal from the ladle. It is kept in a tilted position during the trip back to cupola. This is necessary to prevent the slag from passing into the teapot spout and thence into the castings at the next pour. The use of a cover on the ladle during the travel to and from the cupola generally will conserve 50 or more degrees temperature at the casting floor.

## VARIATIONS IN DESIGN AND LAYOUT

28. The variations in the design and lay-out of forehearths or teapot ladle equipment with relation to the cupola assembly are

FIG. 10 — DEEP-TYPE TEAPOPT LADLE ADAPTED TO FOUNDRIES POURING LIGHT CASTINGS. ABOVE—USE IN A CUPOLA MALLEABLE FOUNDRY. RIGHT—USE IN A FOUNDRY MAKING WASHING MACHINE PARTS.

FIG. 11—6-TON TEAPOT LADLE USED IN A RADIATOR FOUNDRY, SHOWING HOOD AND STACK FOR CARRYING-OFF FUMES.



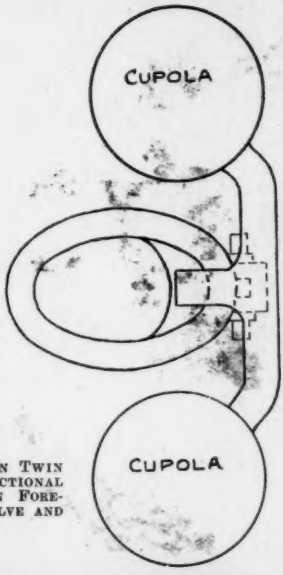



FIG. 12—HINGED FOREHEARTH USED BETWEEN TWIN CUPOLAS IN A PIPE FOUNDRY. ABOVE—SECTIONAL VIEW. RIGHT—PLAN VIEW. BELOW—TWIN FOREHEARTHS USED ON ALTERNATE DAYS IN A VALVE AND FITTINGS FOUNDRY.

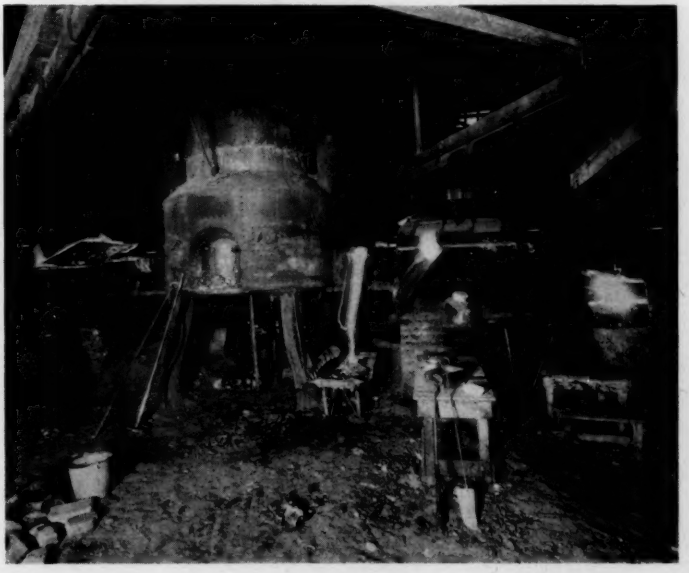


FIG. 13—DEEP FOREHEARTH CONNECTED TO TWIN CUPOLAS IN ORNAMENTAL IRON FOUNDRY.

almost unlimited. This is illustrated in part by typical installations, Figs. 10, 11, 12, 13, 14, 15 and 16, in use at different foundries, covering a wide range of castings.

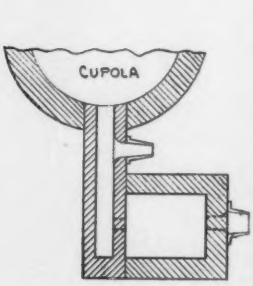


FIG. 14—LEFT—ONE METHOD USED TO ADAPT A FOREHEARTH WITHIN MINIMUM SPACE IN FRONT OF A CUPOLA. RIGHT—STANDARD TEAPOT LADLE USED TO HANDLE LARGE TONNAGES OF HEAVY WORK.

FIG. 15—LEFT—ILLUSTRATION SHOWING SMALL TEAPOT LADLE WITH COVER. RIGHT—MIXING LADLE USED AS A FOREHEARTH.

29. In some foundries, it is the practice to treat only a part of the metal in the heat and pour the remainder direct from the cupola. This is accomplished by offsetting the forehearth, as illustrated at the left in Fig. 17, so that the iron may be passed either through the forehearth or direct into the pouring ladle.

30. There are always some fumes given off when desulphurizing with fused soda ash. These are not usually troublesome in individual ladle treatment or in small tonnage continuous opera-

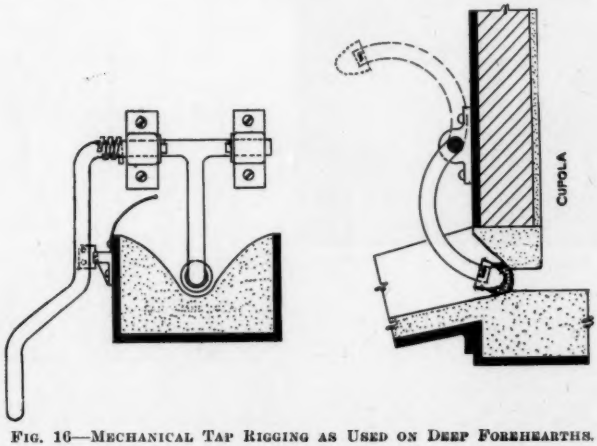



FIG. 16—MECHANICAL TAP RIGGING AS USED ON DEEP FOREHEARTHS.

tions. With melting rates of 15 or 30 tons per hour and continuous, heavy treatment, it is generally necessary to provide some means for removing the fumes from the foundry. This is accomplished by arranging a hood over the ladle or forehearth with a stack leading up through the roof or connected into the cupola shell above the charging doors, as illustrated at the right in Fig. 17. The hood generally is made of sheet iron lined with asbestos, while the pipe section should be painted with a heavy coating of asphalt, tar or asbestos paint as a protection against the fumes.

## LINING MATERIALS AND PRACTICE

31. Generally more attention must be given to the matter of lining materials for forehearths and teapot ladles than in ordinary foundry practice. Mud or molding sand linings cannot be used successfully where the metal is to be desulphurized. Sodium slags attack free silica and clay at the temperature of cupola metal and react to form silicates. However, this action is much less pronounced on dense, hard-burned fire brick of similar composition. Therefore, it is important to reduce the use of mud to a minimum in lining the refining reservoir; first, because it is rapidly cut out

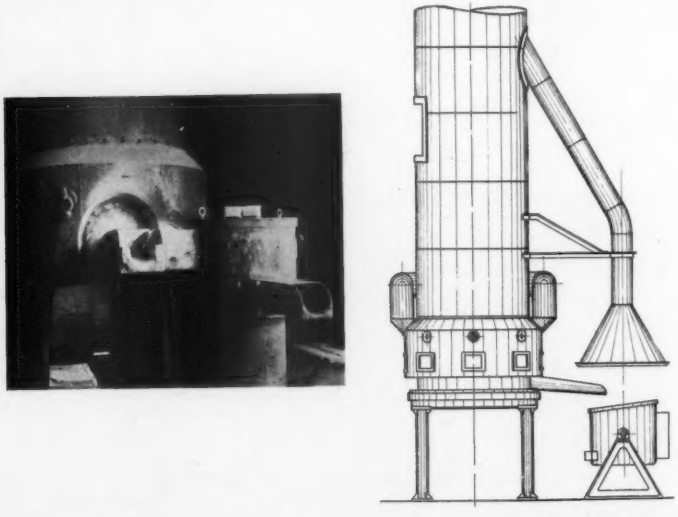


FIG. 17—LEFT—AN OFFSET FOREHEARTH DESIGNED TO DESULPHURIZE ANY PART OF THE HEAT. OTHER PARTS MAY BE TAPPED DIRECTLY FROM THE CUPOLA. RIGHT—VENTILATING HOOD CONNECTED INTO THE CUPOLA STACK ABOVE THE CHARGING DOORS.

by the slag and, second, because of its effect in diluting the refining slag.

32. The reservoir should be lined with two layers of brick—a permanent layer against the shell and a removable inside lining. Dense, hard-burned ladle brick, true to form, such as used by steel mills, have been found to give satisfactory results. The lining should be laid up with a very thin grout, preferably made of the same clay from which the brick were made.

33. Fig. 18 illustrates a section of lining from a 10-ton teapot ladle, laid up as described. Note that the brick joints, which are illustrated by white lines, have been completely cemented, resulting in a practically monolithic lining.

34. A monolithic lining made of rammed gannister sometimes

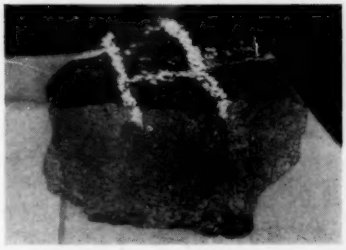


FIG. 18—SECTION OF FIRE-BRICK LINING FROM A 10-TON TEAPOT LADLE SHOWING JOINTS COMPLETELY CEMENTED.

is used with success, especially in smaller installations. Mixtures high in ground brick and silica pebbles, which will expand rather than contract upon heating and thus prevent cracking, are recommended. The mixture should be used at the temper of molding sand and rammed up to a minimum thickness of 5 ins. in small installations or 7 to 9 ins. in larger equipment.

35. It is not to be expected that a forehearth or teapot ladle installation is the solution of every foundry problem. However, where this process seems desirable either as a refining medium or from the standpoint of mixture savings, it is generally possible, with the use of a little ingenuity, to design equipment which will fit into the cupola assembly and regular routine of foundry operations.

## DISCUSSION

W. R. JENNINGS[1], *(Submitted in Written Form)*: We have read with much interest the paper by George S. Evans, and wish to express our appreciation of the manner in which this paper was assembled.

The forehearth, as the author states, is a mixing ladle, a storage reservoir, and a desulphurizer, all in one. To the arguments which he presents as to the effect of intermittent tapping on the metal and slag condition, we quite agree, and would cite an experience which the writer has had, before and after installation of a forehearth.

We were making castings of from 10 lbs. up to 3 tons, and on some of the pressure jobs, for extreme pressures up to 3000 lbs. which required a ¾ to 1-in. section, we found minute slag inclusions at times when using our regular practice. These apparently gathered in the last area in which the metal set, and leakers would develop at that point. However, after installation of a forehearth and using a desulphurizing agent, the violent agitation of the metal, along with the pressure of the volume, apparently caused these inclusions to rise to the top of the batch, and castings produced by metal drawn-off from the bottom of the forehearth showed a very decided improvement in this respect. It also was noted that there was less variability from one ladle to another.

Of course, those operating a receiving ladle will get similar results if they are using a teapot spout. However, the value of either a receiving ladle or a forehearth is measured by the number of cupola charges which the forehearth can hold. Normally, we suggest that the forehearth should hold at least four normal molten cupola charges. This will insure a well mixed bath.

To check the variability of your cupola operation, make up a small wedge test bar of approximately 22½ degrees angle, about 6 in. long, and ⅜ in. wide at the heavy portion. Have these made up in a core, and test each ladle of iron for one day. If you are not using a forehearth or a receiving ladle, you will be very much surprised at the variation in the chill which you obtain on the fine edge of this bar. This will show you why your castings vary in Brinell hardness from one ladle to another. The cupola is erratic, due to a number of conditions, and these we must recognize as existing. The forehearth or receiving ladle will smooth off these variations and make your metal a more continuous and uniform product.

There is another use for the forehearth which the author has not cited, except to mention that the forehearth will smooth out the curve of silicon and carbon and sulphur control. It is possible also to add a carburizer to your forehearth and obtain a very definite carbon pickup. We know of one installation where this was carried out quite successfully, and as much as 0.10 per cent carbon was picked up in the forehearth when this additional carbon was required.

GEO. S. EVANS: In replying to Mr. Jennings' discussion, we wish to say that the effect of the refining in reducing leaky castings, as described by Mr. Jennings, is probably one of the most generally noticeable effects of the action of soda ash slags upon cast iron, other than desulphurizing

[1] Ecorse Foundry Co., Detroit.

which is shown by analysis. This action no doubt results from the combined effect of removal of entrained inclusions and gases which tend to segregate in the heavier sections of the casting, which are the last to solidify.

Concerning the size of forehearth, generally this should provide for the maximum capacity and depth of bath or head pressure consistent with the loss of temperature that is permissible for pouring the castings. However, experience has shown that it is impractical to establish a fixed ratio of forehearth capacity to weight of the cupola charge or to melting rate per hour. We know of several installations operating very successfully with bath capacities of less than one cupola charge. The refining tends to normalize sulphur contents. The pool of metal in the ladle or forehearth is gradually changing, instead of being all tapped out from the cupola at once, and this tends to flatten out variations in composition even though the bath is actually less than the weight of one charge. In other words, while larger capacities are desirable, there are instances, as brought out in the paper, where smaller installations will better serve the purpose.

F. W. SHIPLEY[2], (*Submitted in Written Form*): Mr. Evans' paper is well written and he should be complimented on its concise and compact form. In paragraph 18, the author states that some foundries keep burners in forehearths going throughout the heat, not for an increase in fluidity but rather because they feel they obtain some refinement of structure of the iron. How does the author explain this phenomenon?

In paragraph 20, the author states that "In the production of chunky work, a reduction of upwards of 50 to 60 per cent sulphur present is thoroughly practical. However, it is impractical to go much beyond 30 or 35 per cent in the production of light work and in some instances 15 per cent may prove to be the top limit." Is it not true that the amount of sulphur reduction is governed directly by the amount of temperature drop which one can sacrifice according to the section of the castings he is making?

We believe that if sulphur is detrimental at all it is most harmful in thin section castings and therefore the per cent of reduction should be greater than in any other case. In other words, the final sulphur analysis should be lower. A temperature drop of even 50 or 75 degrees in the case of irons running 3.10 per cent total carbon and under 0.20 per cent phosphorous is a serious matter, especially in castings of light sections.

GEO. S. EVANS: Replying to Mr. Shipley, it was not the author's purpose to state "as a fact" that operation of the burners throughout the duration of the heat improved physical properties but rather to record results as reported by other observers. It is possible, however, that the increased activity of the slag resulting from applied heat would, under certain conditions, result in sufficient added refining to show up in the grain structure of the finished casting.

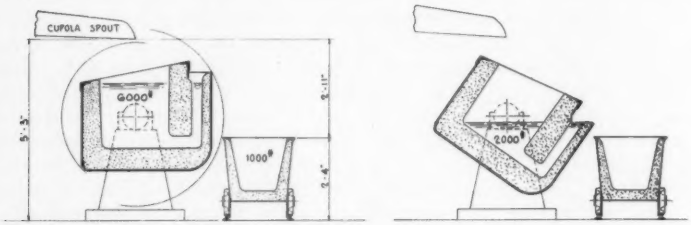
Generally speaking, the amount of sulphur reduction possible in any given instance generally is governed by the temperature drop that is permissible. However, it does not necessarily follow that the percentage of sulphur reduction in light castings should always be greater than in metal

[2] Metallurgist, Caterpillar Tractor Co., Peoria, Ill.

for heavier work. For instance, the primary object of desulphurizing metal for ingot molds is to reduce surface cracks resulting from extreme temperature changes, and secondarily, in order that the scrap mold, after it has served its life, can be used in the openhearth charge in place of pig iron. In certain other cases, the greatest value of the refining is due to removal of entrained impurities, including sulphur, with resultant benefits as mentioned by Mr. Jennings.

In the production of light castings, such as radiator sections and stove plate, where fluidity of the metal, soundness and machinability of the finished casting, are generally of prime importance, obviously, the extent of desulphurizing should be regulated as required to meet those conditions.

C. C. KAWIN[3], (*Submitted in Written Form*): I have read this paper very carefully and it is very interesting, but if foundrymen are going to




TYPICAL LAYOUT FOR 6000-LB. CAPACITY ELLIPTICAL TEAPOT RESERVOIR LADLE SHOWING HEADROOM REQUIREMENTS.

obtain the full benefit of this, they must understand that they should study it thoroughly, and that no subject of any value can be learned in one lesson.

Desulphurizing, or the elimination of sulphur, is just as practical as the addition of silicon, manganese, or any of the other alloys. There are, of course many points to be taken into consideration that is, to watch the fluidity of the slag and variations in temperature from the cupola to the forehearth, but anything that is worth while naturally requires some careful attention.

MR. EVANS: In the general discussion the question has been asked as to the headroom requirements for operating a teapot ladle. The minimum headroom needed for a teapot ladle of 6000-lb. capacity, pouring into a 1000-lb., truck-type, transfer ladle, is shown in the accompanying figure.

This provides for maintaining a bath of 2000 lbs. of metal in the ladle during the heat. The last iron is taken away in shank ladles. For each 1000 lbs. increased capacity, an additional 2½ in. headroom is required.

[3] President, Chas. C. Kawin Co., Chicago.

# Some Problems of the Physical Chemistry of Steel Making†

By

P. Herasymenko* and E. Valenta,** Plsen, Czechoslovakia

**Abstract**

*In this paper, the authors discuss the amount of oxidic inclusions which may be expected in steel. They take up separately steel made in the acid open-hearth and in the basic electric furnace. Equilibrium equations are presented, and reaction rate constants are determined. From these equations, the amounts of the different oxides present can be calculated, and the tables given show close agreement between the calculated values and those found experimentally. The authors study the equilibrium relations between the different constituents of steel, and also between the steel and the slag. A section is devoted to the evolution of gas in molten steel, and theories are advanced to explain this phenomenon. Among the topics taken up are the concentration of iron oxide in acid open-hearth, and in basic electric steel; the relation between silicon and manganese; the reduction of silicon; the equilibrium between the steel and the slag; the fluid silicate and solid silica inclusions. The tests were carried out on carbon steels, from 0.18 per cent to 0.40 per cent carbon.*

1. Among the factors which influence the quality of steel, great importance should be given to the total amount, the form (shape) and the distribution of nonmetallic inclusions in solid metal. The amount of non-metallic elements can be controlled by a suitable course of metallurgical processes in the molten metal.

† Exchange Paper Presented on Behalf of the Czechoslovakian Foundrymen's Association.

* Physical chemist and metallurgist, Research Institute of Skoda Works, Ltd.

** Head of the Research Institute, Skoda Works, Ltd.

Note: This paper was presented at one of the sessions on Steel Founding at the 1934 Convention of the A.F.A.

The time usually allowed for the elimination of nonmetallic inclusions during solidification in the ingot mold is too short, so that the total amount of nonmetallic elements in the solid metal is not much less than that present in the ladle before pouring. The rate of cooling the metal in the mold influences mainly the distribution of inclusions, and to some extent, their shape.

2. In this paper the authors intend to discuss, on the basis of some experimental facts, what minimum amount of oxidic inclusions can be expected, when producing steel in the acid open-hearth and in the basic electric furnaces.

3. The authors present some considerations on the equilibria between acid open-hearth slags and metal. The knowledge of these equilibria is very important, in view of the fact that oxidic nonmetallic inclusions have a composition very similar to that of the acid slag. A chapter is dedicated to the discussion of the cause of gases in steel, and its relation to the composition of inclusions.

## IRON OXIDE DISSOLVED IN ACID OPEN-HEARTH STEEL

4. From the equilibrium equation

$$FeO + C \leftrightarrows CO + Fe$$

it could be expected that with decreasing carbon content, the amount of iron oxide dissolved in liquid steel will increase. The rate of carbon elimination is given by the difference of reaction rates in both directions:

$$v = -\frac{d\,[C]}{dt} = k_1\,([FeO] \times [C]) - k_2\,([Fe] \times p_{co})$$

Here $k_1$ is the rate constant of the reaction between carbon and iron oxide; $k_2$ is the reaction rate constant of the interaction between carbon monoxide and iron; $p_{co}$ is the pressure of carbon monoxide.

5. At equilibrium, *i. e.* when $v = -\frac{d\,[C]}{dt} = 0$, we obtain

$$\frac{p_{co} \times [Fe]}{[FeO] \times [C]} = \frac{k_1}{k_2} = K$$

Since [Fe] = constant, we may write

$$k'_2 = k_2 \times [Fe]$$

$$v = -\frac{d\,[C]}{dt} = k_1 \times [FeO] \times [C] - k'_2 \times p_{co} \qquad (1)$$

and

$$\frac{p_{co}}{[FeO] \times [C]} = \frac{k_1}{k'_2} = K' \qquad (2)$$

6. By the use of these equations, Herty[1*] has made an attempt to calculate the equilibrium constant K′ from the rate of carbon elimination in open-hearth furnaces and from the determinations of iron oxide by the hydrogen reduction method. Schenck, Riess and Bruggemann[2] have repeated the same experiments, but for the determination of iron oxide have used the aluminum method, which was in the meantime developed by Herty[3].

7. These investigators have stated that the equilibrium and the reaction rate constants of this reaction do not really depend on the temperature, but depend on the total concentration of carbon in the melt. The explanation the authors propose for the latter fact is as follows.

8. "The rate and the equilibrium constant of the process $FeO + C \leftrightarrows Fe + CO$ which takes place in liquid iron between 1500 and 1650 deg. Cent. (2730 to 3000 deg. Fahr.) can be expressed mathematically by assuming that carbon dissolved in iron is present partly in atomic form and partly in form of polymerized carbide molecules $Fe_3C_6$.

## CALCULATION OF IRON OXIDE CONTENT

9. The values of the equilibrium and reaction rate constants as determined by Schenck and his collaborators allow us to calculate the amount of iron oxide dissolved in liquid steel, if the rate of carbon elimination and the total concentration of carbon at a given instant is known. For this purpose, we use equation (1), which can be written as follows:

$$[FeO] = \frac{v + (k'_2 \times p_{co})}{[\Sigma C]^* \times k_1}, \qquad (3)$$

* $\Sigma C$ is the total concentration of carbon in the melt.

10. One of us, in collaboration with Pondelik,[4] verified the validity of this formula and the reaction rate constants obtained by Schenck by measuring the actual content of iron oxide in liquid openhearth steel at different stages of melting process, using the aluminum method. In that paper a modification of Herty's analytical procedure was described, because the original method gives inconsistent results when applied to alloy steel.

[1*] Superior Numbers indicate references in the bibliography at the end of the paper.

11. The agreement attained between the experimentally determined and calculated concentrations of iron oxide may be judged from the data given in Table 1, which were taken on two heats of an acid nickel-chromium-molybdenum steel. (No additions of ore, ferromanganese or ferrosilicon were made to the metal during the whole process). The table clearly shows that the amount of iron oxide at the end of the melting process is considerably more than at the beginning.

**Table 1**

DIFFERENCE BETWEEN ACTUAL AND CALCULATED IRON OXIDE CONTENT

| Test* No. | Time (minutes) | C Per Cent | V (Per Cent per minute x $10^6$) | FeO found Per Cent | FeO calculated Per Cent | Difference Per Cent |
|---|---|---|---|---|---|---|
| 1A* | 0 | 0.97 | ... | .... | .... | .... |
| 2A | 60 | 0.95 | 25 | 0.022 | 0.023 | —0.001 |
| 3A | 120 | 0.92 | 63 | 0.034 | 0.025 | +0.009 |
| 4A | 180 | 0.88 | 150 | .... | 0.029 | .... |
| 5A | 240 | 0.72 | 300 | 0.044 | 0.040 | +0.004 |
| 6A | 295 | 0.56 | 325 | 0.043 | 0.047 | —0.004 |
| 7A | 330 | 0.42 | 325 | 0.055 | 0.055 | 0.000 |
| 1B | 20 | 1.01 | 91 | 0.030 | 0.025 | +0.005 |
| 2B | 75 | 0.97 | 153 | 0.031 | 0.027 | +0.004 |
| 3B | 135 | 0.75 | 405 | 0.046 | 0.045 | +0.001 |
| 4B | 195 | 0.56 | 230 | 0.049 | 0.045 | +0.004 |
| 5B | 230 | 0.50 | 191 | 0.046 | 0.042 | +0.004 |

* Test numbers marked A and B are from heats A and B respectively.

12. The course of the pick-up of iron oxide in three acid nickel-chromium-molybdenum heats has been given by Herty and Jacobs[5]. The values for the content of iron oxide found by these authors were considerably higher than the contents calculated according to Schenck's formula. It was shown, however, that the original analytical procedure in determination of iron oxide by the aluminum method gives high values, if alloying elements (especially molybdenum) are present in the steel.

13. Recently the validity of Schenck's formula was confirmed by several German metallurgists at a discussion at Dussoldorf[5]. The mechanism of the reaction between carbon and iron oxide in liquid steel as depicted by Schenck may be open to criticism, but equation (3) and the numerical values for the reaction rate con-

stants given by Schenck, when applied to open-hearth heats, allow us to calculate the correct content of iron oxide in liquid steel with the same precision as in an experimental determination.

14. The minimum content of iron oxide for a given concentration of carbon in open-hearth steel will be attained when the rate of carbon elimination is approaching zero. Lower values than those corresponding to the equilibrium $FeO + C \leftrightarrows Fe + CO$ cannot be obtained in normal practice in the open-hearth process.

## Iron Oxide Content at Equilibrium

15. The equilibrium values of iron oxide content for different concentrations of carbon in liquid steel are given in Table 2. This table also gives the values for the reaction rate constants. It is noteworthy that the equilibrium and recation rate constants are practically independent of temperature.

**Table 2**

Equilibrium Concentration of C and FeO in Liquid Steel from Open-Hearth Furnace

| C | FeO | $k_1$ | $k'_2 \cdot p_{co}$ | K Equilibrium Constant |
|---|---|---|---|---|
| 0.1 | 0.121 | 0.416 | 0.00504 | 91.0 |
| 0.2 | 0.061 | 0.414 | 0.00503 | 90.5 |
| 0.3 | 0.043 | 0.388 | 0.00501 | 85.3 |
| 0.4 | 0.035 | 0.357 | 0.00498 | 78.9 |
| 0.5 | 0.030 | 0.332 | 0.00495 | 73.8 |
| 0.6 | 0.027 | 0.301 | 0.00490 | 67.5 |
| 0.7 | 0.025 | 0.271 | 0.00485 | 61.6 |
| 0.8 | 0.024 | 0.250 | 0.00479 | 57.5 |
| 0.9 | 0.022 | 0.232 | 0.00472 | 54.1 |
| 1.0 | 0.021 | 0.220 | 0.00466 | 40.5 |

16. As will be shown later, carbon in moderate concentrations and at temperatures of approximately 1600 deg. Cent. (2912 deg. Fahr.) is a more powerful deoxidizer than either manganese or silicon.

17. A typical diagram of the rate of carbon elimination and of the pick-up of iron oxide in an acid open-hearth heat is given in Fig. 1. The curve denoted by [FeO] represents the experimentally determined content of iron oxide in the melt, whereas the dotted line ([FeO] eq.) shows the amount of iron oxide which would be present in the bath if there were an instantaneous equili-

brium between carbon and iron oxide. It is seen that there was practically no removal of iron oxide, *i. e.* no deoxidation; on the contrary, the content of iron oxide at the end of the heat was higher than at the beginning, but, nevertheless, the heat was tapped from the furnace without any addition of deoxidizer and the ingots solidified in a "dead killed" condition.

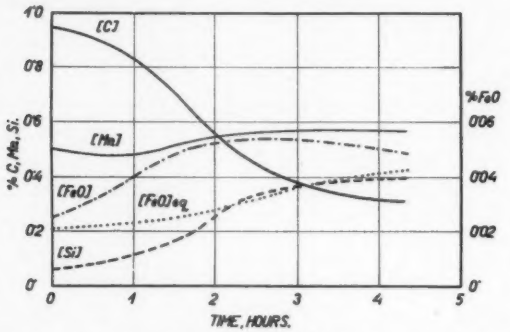



FIG. 1—CHART OF ACID OPEN-HEARTH HEAT. TESTS SOLIDIFIED IN DEAD-KILLED CONDITION AFTER 2 HOURS.

18. Similar results for two acid open-hearth heats were obtained by P. Bardenheuer[6].

19. These arguments put the problem of deoxidation in the acid open-hearth furnace in a very different position from the usual conception in that matter. As an example of the erroneous views on deoxidation in an acid open-hearth furnace held by many metallurgists until recently, we may quote the following sentences written by F. Beitter[7]:

20. "The procedure which is termined deoxidation aims to reduce the amount of oxygen dissolved in the melt. . . . The deoxidation in acid open-hearth furnace takes place spontaneously and requires small or even no addition of a deoxidizer in the furnace."

21. The reasons which led to the misconception on the deoxidation phenomena in the acid open-hearth process were as follows:

(a) the content of silicon in acid steel increases at the end heat and this was thought to be the cause of the decrease of iron oxide content,

(b) the heat tests at the end of some acid heats show that steel solidifies without evolution of gases (killed condition) and this was ascribed to the diminution of iron oxide content.

In further chapters the present authors propose to explain these phenomena.

## EQUILIBRIUM BETWEEN IRON AND SLAG

22. Acid slag represents a solution of oxides of iron, manganese and silicon which are present partly free and partly in the combined state. All that can be said at present is that the amount of free oxides of iron and manganese represents only a small fraction of the total analytical concentration of these oxides in acid slag. Very little is known about the true nature of these solutions. An attempt to calculate the dissociation constants of the silicates of iron and manganese made by Schenck[8] cannot be regarded as sufficiently exact, because the processes in industrial furnaces are very far from equilibrium and because of the uncertainty of many suppositions necessary for such calculations.

23. Equilibrium between acid slag and iron containing manganese and silicon can be attained only under special conditions, of which the simplest case is the equilibrium between solid silica, liquid acid slag containing oxides of iron, manganese and silicon, and liquid iron containing manganese and silicon and no carbon.

24. According to the phase rule, this latter system has two degrees of freedom and therefore the concentration of all components in the liquid iron and slag is determined by the concentration of one component (*e. g.* manganese) and by the temperature.

25. A very thorough investigation of this system was carried out by Körber and Oelsen[9]. These authors have found that the solubility of silica in acid slag is approximately 50 per cent (by weight) of $SiO_2$, therefore the sum of iron oxide and manganese oxide is also equal to 50 per cent. The equilibrium composition of slag and metal for various temperatures, independent of the content of manganese in the metal phase, is shown in Fig. 2. The results of Körber and Oelsen show that the main reactions participating in equilibrium are as follows:

$$Mn + FeO \leftrightarrows Fe + MnO, \qquad (4)$$

$$2MnO + Si \leftrightarrows 2Mn + SiO_2, \qquad (5)$$

$$2FeO + Si \leftrightarrows 2Fe + SiO_2, \qquad (6)$$

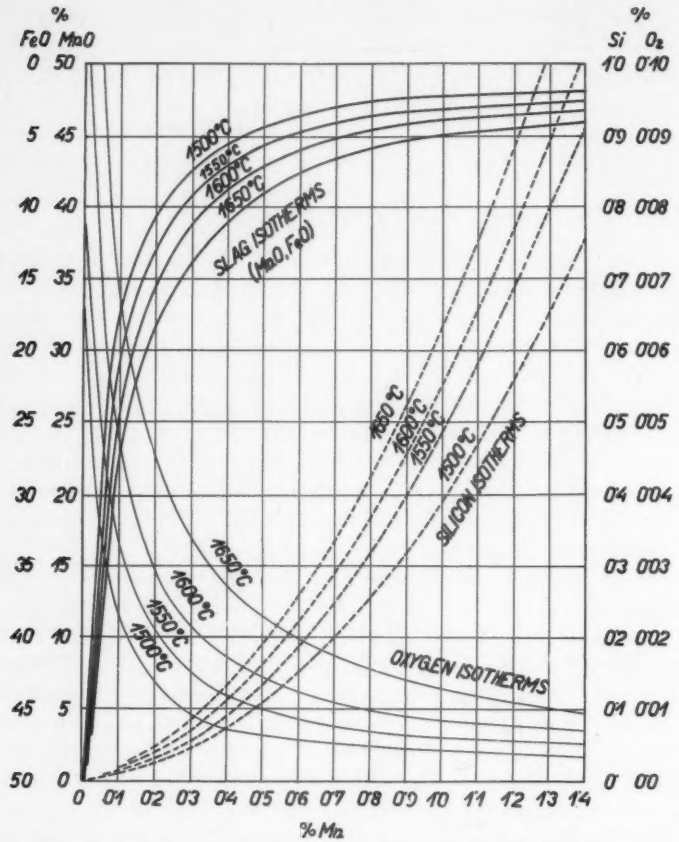



FIG. 2—COMPOSITION OF SLAG AND METAL IN THE SYSTEM Fe-Mn-Si-O IN EQUILIBRIUM WITH SOLID SILICA (ACCORDING TO KORBER & OELSEN)

26. Since at low concentrations of manganese and silicon in the metal, the concentration of iron can be put equal to 100 per cent, and because the concentration of silica in the slag is constant, the equilibrium constants of these reactions can be written as follows:

$$K_{Mn} = \frac{(MnO) \times 100}{[Mn] \times (FeO)}, \qquad (4a)$$

$$K_{SiMn} = \frac{[Si] \times (MnO)^2}{[Mn]^2}, \qquad (5a)$$

$$K_{Si} = (FeO)^2 \times [Si], \qquad (6a)$$

## RELATION BETWEEN SILICON AND MANGANESE

27. Strictly speaking, the concentrations of slag components in these formulae should represent the contents of free (uncombined) oxides. Körber and Oelsen have shown, however, that—if instead of the content of free oxides, the total analytically determined contents of oxides are substituted in these equations—the values of $K_{Mn}$, $K_{SiMn}$, $K_{Si}$ are actually constant, as far as the accuracy of experimental results permits. Thus, we have to consider the relations found by Körber and Oelsen as empirical ones which can very satisfactorily describe the observed phenomena.

28. Constants $K_{Mn}$, $K_{SiMn}$, $K_{Si}$ depend on the temperature according to the equations:

$$\log K_{Mn} = \frac{7940}{T} - 1.172 \qquad (4b)$$

$$\log K_{Si} = -\frac{19057}{T} + 11.1008 \qquad (5b)$$

$$\log K_{SiMn} = -\frac{3177}{T} + 4.757 \qquad (6b)$$

29. From Fig. 2, an interesting relationship follows, viz. that the content of silicon in metal increases very rapidly with the increase of manganese concentration. At a manganese content over 0.4 per cent, the relative changes in slag composition are very small, whereas the relative changes in the content of silicon are considerable. This shows that the reaction

$$SiO_2 + 2Mn \rightarrow Si + 2MnO \qquad (7)$$

is of predominant importance in determining the reduction of silicon from slag.

30. Because the concentrations of manganese oxide and silica in the slag are comparatively large, and because the equilibrium of the above reaction is only slightly influenced by the temperature, it can be expected that this equilibrium can be reached more easily than the equilibria of reactions (4) and (6), even in industrial furnaces in the presence of carbon. In other words, the content of silicon in acid open-hearth steel should be given by the equation:

$$[Si] = \frac{K_{SiMn} \times [Mn]^2}{(MnO)^2} \qquad (8)$$

31. The same conclusion was reached by the present authors

from the study of reactions in acid open-hearth furnace, independently of the work of Körber and Oelsen. The course of the reactions in this case was complicated by the presence of carbon.

## REDUCTION OF SILICON

32. In order to illustrate the conditions leading to the reduction of silicon in the acid open-hearth furnace, the results of our measurements at the temperature of approx. 1650 deg. Cent. (3000 deg. Fahr.) are shown in the Figs. 3 and 4.

33. Only those heats were chosen for this compilation in which no addition of ore, lime, sand, ferro-manganese, ferro-silicon or spiegel were made from the beginning of the melt until the time at which the test samples were taken. Further, our results refer only to those heats in which slag contained a small percentage of lime (maximum 1.5 per cent CaO). The temperature on the surface of steel in the ladle was measured by means of an optical pyrometer immediately after the steel sample was taken out of the furnace. The non-corrected readings of the temperature of the results given in diagrams was 1530 $\pm$ 10 deg. Cent. (2785 $\pm$ 16 deg. Fahr.).

34. The rate of silicon reduction from slag is considerably influenced by the agitation of slag and the metal bath. When the slag becomes quiet—as in the case at the end of heat before tapping,—the reduction of silicon from slag and its distribution in the bath proceeds extremely slowly, owing to the insufficient rate of diffusion. Therefore, only those test samples were chosen for further consideration which were taken in the boiling period or just at the end of it.

35. The rate of carbon elimination was approximately the same in the experiments represented in Figs. 3 and 4. The content of carbon varied within narrow limits (0.50-0.30 per cent). Therefore, it is easily understood why the content of iron oxide dissolved in the metal bath varies only within narrow limits (0.04-0.06 per cent). As is seen from the diagram, there exists a pronounced regularity in the composition of slag and metal, independent of the manganese content.

36. The comparison of our diagrams with corresponding curves given by Körber and Oelsen shows that the presence of carbon in acid steel considerably influences the composition of slag and metal. It is evident that in the acid open-hearth furnace we have to deal only with stationary states which are determined by

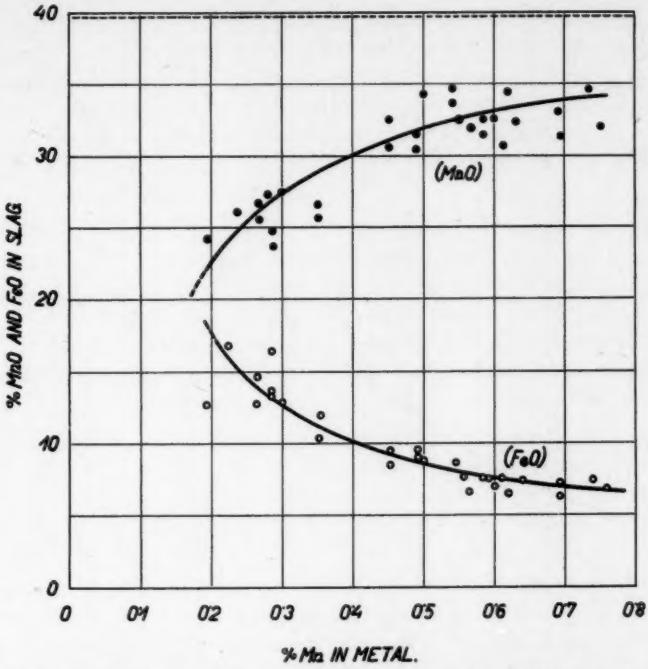



FIG. 3—COMPOSITION OF ACID SLAG AT APPROX. 1650 DEG. CENT. (3000 DEG. FAHR.) AT THE END OF THE BOILING PERIOD. 0.0 TO 1.5 PER CENT CaO IN THE SLAG, 0.30 TO 0.40 PER CENT C IN THE STEEL.

the rate of diffusion of reacting substances in both phases. Only one reaction, *viz.* $2MnO + Si \leftrightarrows Mn + SiO_2$ is very near to the state of equilibrium, as may be shown in the following examples.

37. The equilibrium constant $K_{SiMn}$ at approximately 1650 deg. Cent. (3000 deg. Fahr.) according to Körber and Oelsen, is $K_{SiMn} = 1300$. The content of silicon calculated according to equation (8) is in very good accord with the observed content of silicon.

38. Owing to the presence of carbon, the distribution of iron oxide between slag and metal is far from equilibrium. Thus, for example, the content of iron oxide in slag corresponding to 0.20 per cent of silicon in metal, according to the value of equilibrium constant $K_{Si} = 157$ at 1650 deg. Cent. (3000 deg. Fahr.) should be 8 per cent iron oxide. Actually, much higher contents of iron oxide in slag were observed (10 to 12 per cent—see Fig. 3). Liquid iron in the absence of carbon can contain, at a given content of

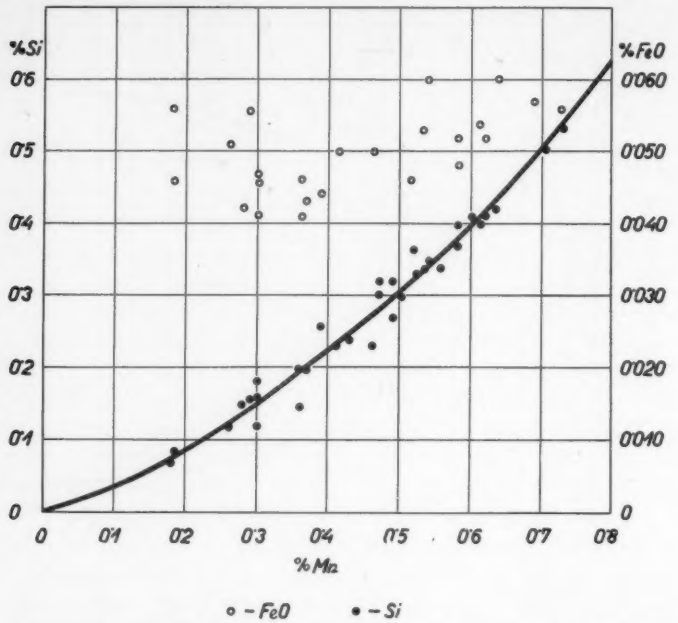



FIG. 4—COMPOSITION OF ACID STEEL AT END OF THE BOILING PERIOD AT APPROX. 1650 DEG. CENT. (3000 DEG. FAHR.) 0.30 TO 0.40 PER CENT C IN THE STEEL.

silicon and manganese, a higher amount of dissolved iron oxide than is actually observed in acid steel. Consequently, carbon dissolved in liquid steel acts more strongly on the elimination of iron oxide than do silicon or manganese present in usual concentrations.

## IRON OXIDE CONCENTRATION

39. The reaction of silicon and manganese with dissolved iron oxide can take place to a considerable extent only at low concentrations of carbon or at low temperatures. In this latter instance

**Table 3**

CALCULATED AND OBSERVED SILICON CONTENT

| Mn Per Cent | MnO Per Cent | Si Per Cent Calculated | Si Per Cent Observed |
|---|---|---|---|
| 0.20 | 23.0 | 0.097 | 0.09 |
| 0.40 | 27.0 | 0.230 | 0.23 |
| 0.60 | 33.0 | 0.430 | 0.39 |

—owing to strong temperature influence on the equilibria $2FeO + Si \leftrightarrows 2Fe + SiO_2$ and $Feo + Mn \leftrightarrows Fe + MnO$ — the action of silicon and manganese on iron oxide is more important than that of carbon since the equilibrium of the reaction, $FeO + C \leftrightarrows Fe + CO$, is independent of temperature. The formation of non-metallic inclusions in the bulk of metal during cooling and freezing will be discussed in the next chapter.

40. At present we wish to stress again that the foregoing discussion and regularities observed in acid open-hearth furnace apply only to the case when both slag and metal are in equilibrium, or at least tend to be in equilibrium, with solid silica (walls of the furnace). A number of other experimental conditions can be imagined in which solid silica is entirely absent. Thus, for example, a very ingenious method of removal of iron oxide from highly oxidized steel was described recently by Perrin[10].

41. This method consists of a violent stirring of metal with a very fluid slag almost completely devoid of oxides of iron and manganese and containing only lime, silica and magnesia.

42. At the beginning of the melting period, the tests cast into small chill molds solidify with the evolution of gases. At a certain period this evolution of gases ceases and steel is then called "killed." The diagram of the heat given in Fig. 1 shows that during the period when the tests solidified with the evolution of gases, the bath contained lower percentage of iron oxide than in the following period when tests appeared killed. These facts prove decisively that the appearance of the heat test on solidification gives no indication as to the actual content of iron oxide dissolved in the bath.

43. In order to establish the cause of the quieting of steel, we have compiled the data on gas evolution from heat tests from log charts of a great number of acid heats. To avoid unnecessary complications, only those heats were taken into account which were conducted without the addition of ore, ferro-manganese or ferro-silicon in the bath. Subsequently it was found that the regularities described below hold also in the latter case, and also for basic open-hearth heats.

44. The results are plotted in Fig. 5. (Full circles represent the heat tests which solidified in the mold with no sparking or bulging of the upper surface; the empty circles refer to the tests which solidified with gas evolution.)

## EXPLANATION OF GAS EVOLUTION

45. The results show that the gas evolution depends on the contents of carbon, manganese and silicon. As already mentioned there is no direct connection between gas evolution and the amount of iron oxide. The tendency of acid steel to evolve gases during solidification increases with increasing concentration of carbon and manganese and decreases with increasing content of silicon.

46. The problem of gas evolution during solidification was discussed at length in the Fourth Report on the Heterogeneity of Steel Ingots[11]. The following explanation was considered most probable:

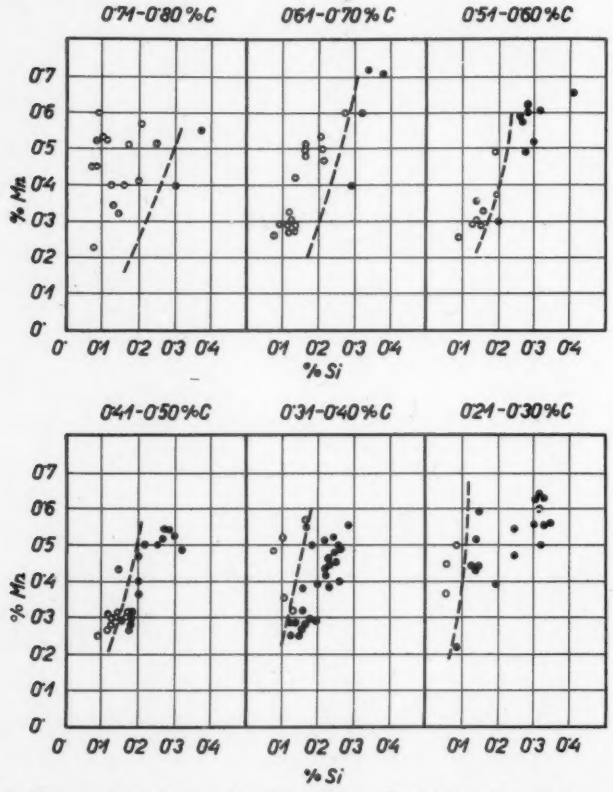



FIG. 5—EVOLUTION OF GAS IN ACID HEAT TESTS, O—GAS EVOLVING STEEL. DEAD MOLTEN STEEL.

47. "At lower temperatures, the equilibrium between iron oxide in the metal and iron oxide in the slag is upset, and, as shown by Herty, the amount of iron oxide in solution in the bath is a function of the temperature. At lower temperatures, the excess iron oxide reacts vigorously with the carbon and a rapid evolution of carbon monoxide takes place."

48. Herty[12] has come to the conclusion that "the explanation for rimming of steel in a mold, which, of course, applies equally well to a small test mold, is that a solid surface is required to bring about the carbon-iron-oxide reaction".

49. The above explanations are, however, too indefinite and cannot explain the details of the relationship observed by us.

50. As the cause of the gas evolution which satisfactorily explains the behaviour of acid steel in small test molds, the present authors present the following:

51. When liquid steel is taken out of the furnace in a ladle, it usually contains only a small excess of iron oxide over that which will be in equilibrium with the carbon content of the metal, so that the reaction rate is low. The rapid cooling of the metal brings about, however, the displacement of the oxidation-reduction equilibria for manganese and silicon. These equilibria depend to a great extent on the temperature and therefore the cooling of the metal is accompanied with the separation of silicate inclusions. The composition and the properties of these inclusions will vary with the content of manganese and of silicon in the metal. The iron oxide extracted by silicate inclusions, being now in a more concentrated form, can react with carbon in the metal.

### Reaction Rate Depends on Diffusion

52. The rate of this heterogeneous reaction will depend on the diffusion of reacting substances towards the surface of inclusions. The diffusion rates are in turn influenced by the total concentration of reacting substances and by the viscosity of both phases. It is evident now that the higher the content of carbon in the metal, the greater will be the tendency toward evolution of gas.

53. The chemical composition and viscosity of silicate inclusions depend on the initial concentration of manganese and silicon in the metal.

54. From investigations of C. H. Herty it is known that fluid silicate inclusions form, when the metal contains manganese

and silicon in a definite ratio (manganese is to silicon as 1/4 to 1/7).

55. The more fluid are the inclusions formed in steel on cooling, the more lively will be the reaction of iron oxide dissolved in the inclusions with the carbon in the liquid steel.

56. A qualitative course of the formation of oxidic inclusions in liquid steel can be derived from the diagram given by Körber and Oelsen (See Fig. 6). The heavy curve of this diagram indicates the compositions of liquid metal which is in equilibrium with solid silica and liquid silicate slag at approximately 1500 deg. Cent. (2730 deg. Fahr.). In the region above this curve are formed only solid silica inclusions, and in the region below this curve are separating only liquid silicate inclusions. The crystallisation of metal of a given composition (without carbon) takes place approximately along the straight lines passing through the origin of

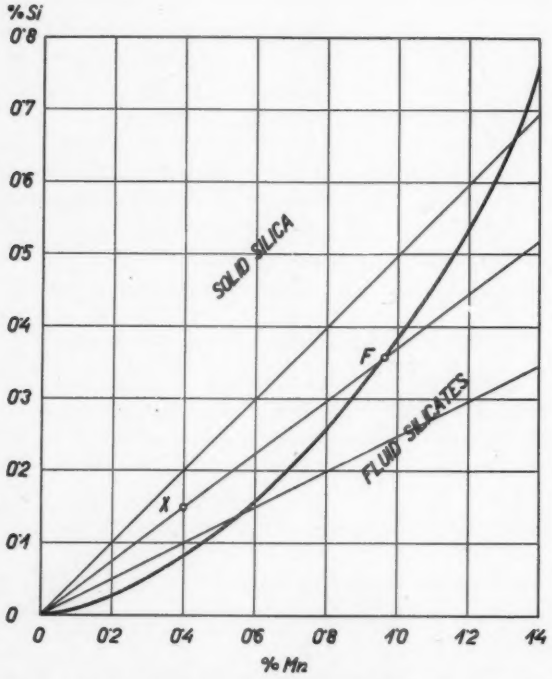



FIG. 6—SCHEME OF STEEL CRYSTALLISATION AND SEPARATION OF SILICATE INCLUSIONS (ACCORDING TO KORBER & OELSEN).

coordinates and the point corresponding to given contents of silicon and manganese.

57. Thus, for example, the crystallisation of iron originally containing 0.40 per cent manganese and 0.15 per cent silicon (point X in Fig. 6) proceeds in the direction X F, which means that the composition of the residual liquid metal changes as indicated by the line X F. It is seen that at first the crystallisation is accompanied by the separation of solid silica inclusions; when the liquid portion of metal acquires the composition corresponding to point F, the fluid silicates begin to form. Thus, it is seen that the formation of fluid silicates takes place after a considerable portion of originally liquid steel has been solidified.

58. Therefore, the evolution of carbon monoxide begins to take place in a partly solidified steel according to the mechanism described above. The statement of C. H. Herty quoted above, that

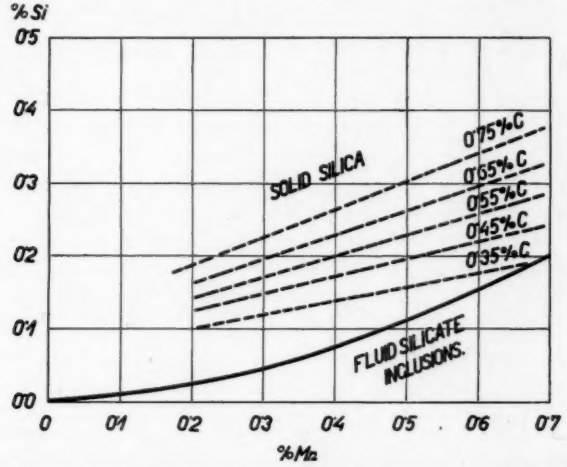



FIG. 7—BROKEN LINES SEPARATE REGION OF DEAD MOLTEN STEELS (ABOVE) FROM GAS EVOLVING STEELS (BELOW) FOR GIVEN CARBON CONTENT. SOLID LINE SHOWS EQUILIBRIUM COMPOSITION OF METAL WITH SOLID SILICA AND FLUID SILICATES AT APPROX. 1650 DEG. CENT. (3000 DEG. FAHR.) (ACCORDING TO KORBER & OELSEN).

a solid surface is necessary to bring about the carbon-iron-oxide reaction, is explained, therefore, in a more plausible manner.

59. In the presence of carbon, the course of crystallisation does not proceed along straight lines as indicated in Fig. 6, and conditions leading to gas evolution are somewhat changed. In Fig. 7 we have plotted the lines separating the regions of gas

evolving steels and those of killed steels at different carbon contents. These curves were taken from Fig. 5 and represent the conditions leading to gas evolution in acid steel in an empirical way. It is worthy of note that our curves are almost parallel to the line of Körber and Oelsen, true for carbonless steels.

60. At the present state of our knowledge on the mechanism of solidification of steel and of the formation of inclusions, a more detailed discussion of our empirical diagram would be premature.

### THE AMOUNT OF IRON OXIDE IN BASIC ELECTRIC STEEL

61. Typical curves of iron oxide elimination from the bath under the reducing slag of the basic electric arc furnace of 6 ton capacity are shown in Figs. 8 and 9.

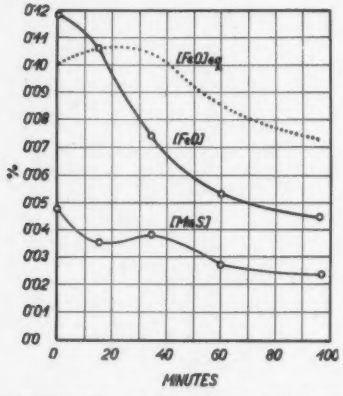



FIG. 8—IRON OXIDE ELIMINATION IN BASIC ELECTRIC HEAT, DURING REDUCTION PERIOD. 0.18 PER CENT CARBON STEEL.

62. Fig. 8 refers to a steel with 0.16 per cent carbon; in this case no recarburisation of the bath was necessary before the reducing slag was formed. During the reduction period the bath took up from the slag only 0.04 per cent carbon. At the moment of the beginning of the reduction, the bath contained 0.12 per cent carbon and 0.117 per cent iron oxide. The latter value was only slightly above the equilibrium value for the reaction $FeO + C \leftrightarrows Fe + CO$. (The equilibrium concentrations of iron oxide for the corresponding carbon contents are denoted in the diagrams by dotted lines). The diagram shows that the amount of iron oxide in the metal decreases rapidly at first. Towards the end

of the heat, the rate of iron oxide elimination becomes slower.

63. Fig. 9 shows a steel with 0.35 per cent carbon. In this case, the bath was recarburized with anthracite after the removal of the oxidizing slag. At the beginning of the reduction period, the bath contained 0.040 per cent iron oxide which again corresponds to equilibrium with 0.32 per cent carbon present at this moment in the bath. The rate of iron oxide—elimination in this

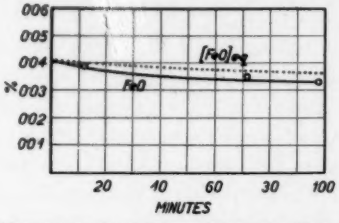



Fig. 9—Iron Oxide Elimination in Basic Electric Heat, During Reduction Period. 0.35 Per Cent Carbon Steel.

case was very slow, and this was invariably found in all cases when the initial concentration of iron oxide at the beginning of the reduction period was approximately 0.040-0.050 per cent. It is interesting to note that also in those cases, where the initial concentration of iron oxide was about 0.10 per cent (low carbon steels), the rate of iron oxide elimination becomes slower on approaching the value of 0.050 per cent iron oxide.

64. Iron oxide elimination from the bath in the reduction period proceeds by diffusion of iron oxide into the slag, which contains only a very small amount of iron oxide, (of the order of 0.1 per cent). Because the rate of diffusion depends on the concentration gradient between slag and metal, it is easily understood that the rate of iron oxide elimination will be faster, the greater is the total concentration of iron oxide in the bath.

65. The measurements of the iron oxide content in the acid open-hearth bath have shown that the amount of iron oxide which can coexist with a considerable concentration of manganese and silicon is of the same order of magnitude as the values observed in the basic electric furnace. Therefore, it would be futile to expect that the additions of manganese or silicon will bring about a diminution in the iron oxide content. This fact was actually confirmed by the measurements of the iron oxide content before and after the additions of usual amounts of ferro-silicon and ferro-manganese.

66. Thus, in the case of basic electric steel, one cannot speak of the deoxidation of steel by the addition of silicon or manganese. The deoxidation, *i. e.*, the diminution of the iron oxide content, in basic electric steel actually takes place because of the action of the reducing slag. In this respect the basic electric furnace differs considerably from the acid open-hearth furnace, because in the latter no diminution of the iron oxide content in the liquid steel is possible below the value corresponding to the equilibrium $FeO + C \leftrightarrows Fe + CO$.

67. On the solidification of steel, almost the total amount of iron oxide which was present in the liquid bath will appear in the metal in form of oxidic inclusions (silicates). Since liquid basic electric steel contains a considerably lower amount of dissolved iron oxide than acid steel, the former is usually much cleaner. The minimum content of iron oxide which can be attained in basic electric steel under a good reducing slag is approximately 0.020 to 0.025 per cent.

## EVOLUTION OF GAS IN BASIC ELECTRIC STEEL

68. The deoxidizing action of manganese and silicon in the metal becomes perceptible only when the temperature of the liquid steel decreases considerably. The silicates of iron and manganese formed in this reaction are dispersed in the metal and are partly entrapped between the dendrites of solidifying steel. The influence of oxidic inclusions on the gas evolution from basic electric

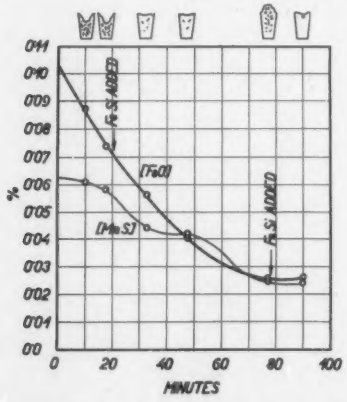



FIG. 10—COURSE OF IRON OXIDE AND MANGANESE SULPHIDE ELIMINATION IN BASIC ELECTRIC HEAT. APPEARANCE OF TESTS SHOWN ABOVE THE CHART.

steel during solidification is the same as explained above for acid steel.

69. Thus, the tests of electric steel with a lower carbon content (0.18 per cent carbon), but of the same content of silicon and manganese, as the steel with 0.35 per cent carbon, appear to be more quiet in the test mold than the latter.

70. However, electric steel is more inclined to the evolution of gases than acid steel having the same contents of carbon, silicon and manganese.

71. The cause of this increased sensitivity can be explained best by considering a typical example, shown in Fig. 10. During the reduction period of this heat, the carbon and manganese content was approximately constant. The first two heat tests after the beginning of the reduction period solidified with sparking. Then, 20 minutes after the commencement of the reduction period, ferro-silicon was added so that the concentration of silicon in the bath rose to 0.05 per cent. Two heat tests which followed this addition were quiet and showed a perfectly flat upper surface on solidification. However, (when fractured these tests had a small number of gas holes). The test cast 55 minutes after the silicon addition showed on solidification a strongly bulging upper surface and the number of gas holes found in the fractured test was considerably larger than in preceding tests. The analysis of this test showed, however, that silicon content remained almost unchanged (0.04 per cent silicon) and the iron oxide content was considerably lower than in the preceding tests. Therefore, the increase in the rate of gas formation could not be due to the state of oxidation of the bath.

### Sulphur Decrease Is Explanation

72. The explanation should be sought in the decrease of the sulphur content (expressed in the diagram as manganese sulphide) towards the end of the heat. J. H. Andrew and collaborators[13] have found that slag systems containing manganese sulphide and manganese silicate have eutectics at a low percentage of manganese sulphide (at about 10 per cent). The inclusions formed during cooling and solidification of steel are thus in reality the liquid solutions of silicates and sulphides. It is to be expected, that at low concentrations of sulphide in liquid metal, the inclusions formed on cooling will show a greater fluidity and therefore will be more active in hastening the reaction $FeO + C \rightarrow Fe + CO$, than the inclusions in a steel with high percentage of sulphide.

73. Of course, the explanation proposed by us is only a schematic one, because the partition of sulphur between liquid metal and oxidic inclusions at the temperature of steel solidification is not known.

74. The average content of sulphur which can be obtained at the end of the reduction period with good desulphurizing slag in the basic electric furnace is 0.010 per cent sulphur. The sulphur content of acid steel is on the whole much larger (0.020 per cent and more).

75. It is thus evident that the proportion of manganese sulphide in nonmetallic inclusions formed in acid steel will be largely different from that in basic electric steel, which will result in a different behaviour of nonmetallic inclusions. In the example shown in Fig. 9, the decrease of manganese oxide from 0.041 to 0.024 per cent produced a marked change in the rate of gas evolution.

ACKNOWLEDGMENT

76. The authors wish to express their thanks to the general management of the Skoda Works, Plzen, for their permission to publish this paper. Sincere thanks are due to Mr. V. Novy, Manager of the Metallurgical Department, and to Dr. J. Korber for their kind help in this investigation.

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## DISCUSSION

*In absence of the author, this paper was presented in abstract form by C. E. Sims, Assistant Director of Research, American Steel Foundries, Indiana Harbor, East Chicago, Ind.*

MR. SIMS: The first part of this paper deals with a number of formulæ for equilibrium constants and reaction rates for the steel making process and the results obtained from research in which these formulæ were used. The high-light of the paper revolves around some rather novel ideas of deoxidization and the mechanism of gas formation. The gas formation spoken of here, is the formation of CO gas in the steel and does not refer in any way to the subject of effervescing steels that are obviously well deoxidized.

In liquid condition, at temperatures around 2900 degrees Fahr., the silicon, manganese and iron oxide exist in the steel without any reaction; the carbon and FeO have come to equilibrium or to a point where they will no longer react and, therefore, there is no gas evolution. If we could cool that material down to the freezing point, there still would be no reaction between the carbon and the iron oxide, because cooling does not upset that equilibrium condition. However, as we cool the steel, the equilibrium relations between the silicon and the FeO and the manganese and the FeO are upset and they react to form silicates. These will be iron-manganese-silicates, the composition of which will vary with the relative proportions of these constituents present. Now the iron oxide of the bath is concentrated in these inclusions, and due to this concentration, will react with the carbon that is present to form CO.

That is a somewhat difficult picture to get and I will repeat. Before any precipitation takes place, the FeO is diluted throughout the body of the metal and no reaction occurs, but as the precipitation takes place, it concentrates at certain focal points, called inclusions. This concentration brings about a different relation between the carbon and iron oxide, so that reaction can take place with the liberation of gas. The more liquid these inclusions are, naturally the more reactive they are and there are certain conditions under which, at the beginning of freezing, the inclusions formed are very refractory and have a high melting point. As precipitation continues, more iron oxides and more manganese oxide are included in the precipitation and the melting point of the inclusions is reduced so that when solidification is partly completed, the inclusions are more liquid than they were at the beginning of solidification. Therefore, under some conditions, gas evolution will not take place until the steel is partly solidified and this obviously will be trapped

F. A. MELMOTH,[1] (*Submitted in Written Form*): Discussions of the problems dealt with in this paper are more commonly to be found in the proceedings of such associations as the Iron & Steel Institute, but they are becoming more and more important to steel founders. The greater the demand upon any metal product, and the wider its scope of application, the more important it is that the manufacturing industry concerned

[1] Detroit Steel Casting Co., Detroit.

possess a complete knowledge of the more scientific details of its processes.

Specifications for steel castings are perpetually increasing in severity. The field of application of steel castings will be in direct proportion to the success with which the product meets this increased severity of demand.

Many of us have known for a considerable time of the remarkable effect of non-metallic inclusions, both in their degree of occurrence, constitution, size and shape, and we know that small as these inclusions are, they exert a controlling influence upon structural formation and therefore upon physical test properties. The present paper, therefore, is extremely opportune, and should be of interest to steel founders.

As electric furnace production in this country for steel foundry purposes is almost entirely of the acid type, it would have been still more interesting had this method of manufacture been included in the present paper. It has been my experience that the occurrence of non-metallic inclusions and their control are not necessarily the same in acid electric and acid open hearth methods of manufacture. This may be due to a variety of causes. The function of time is not negligible, nor is the possible effect of localized high temperature in the neighborhood of the arc upon slag constitution.

To the steel founder, the value of the scientific reasonings in the paper under discussion lies in the degree to which they can be applied to actual steelmaking practice in the foundry. Beginning with paragraph 32 under the heading of "Reduction of Silicon," for instance, is a scientific reasoning of a steelmaking fact which has been observed for a very long time. It is well known that the crucible steelmakers of old times in Sheffield, England, fully understood from the practical viewpoint the process of increasing silicon content in a crucible of molten steel when this steel contained appreciable quantities of manganese, the silicon in this case, of course, being very largely derived at the expense of the containing pot. In acid electric practice, the reduction of silicon into the bath is quite an important practical operating point, and its understanding and control exerts a powerful influence on the physical properties later to be obtained in the resulting metal.

The explanation given (beginning with paragraph 45) of gas evolution from solidifying steel, also should be of very serious interest to a steel foundryman. Under paragraph 51 is given an explanation of acid steel in small test molds in relation to gas evolution, and it may be that a careful study of this paragraph will set the minds of many of our steel founding friends to work along new lines in considering the causes and control of certain types of porosity in steel castings.

The section on the evolution of gas in basic electric steel will, I am afraid, not be of so great a practical interest to American steel founders as would have been the case had it been on acid electric steel. For a good many sound reasons, this latter process has obtained almost a monopoly in the steel founding industry in this country, where electric melting is operated, and of course the physical chemistry is entirely different in the two processes.

I would like, finally to emphasize to my steelmaking colleagues, that

I am sure that the value of this paper will only become available as it is more carefully and rather laboriously studied. Such papers are necessarily complicated, and their value cannot be seen by a casual reading. I should like to congratulate the authors on a clearly stated series of deductions and explanations on a very interesting subject.

MR. SIMS: I think the principles expounded by the authors are worthy of very careful consideration and study. The example given in Fig. 1, where the silicon is reduced from the slag, serves its purpose very well in illustrating equilibrium relations, but I do not think it should be recommended as a matter of practice. There are pitfalls in the way of operating in this manner where silicon is reduced from the slag. One may get a steel that will solidify without any harmful degree of evolution of gas in an ingot mold, but my own experience leads me to believe that such practice will lead to steel that would be very susceptible to gas evolution.

The one point that interested me a great deal was the exposition of the ability of silicon, manganese and iron oxide to co-exist in considerable quantities in steel without any reaction, providing the temperature is fairly high, and this temperature is not excessive for steel making processes. This is quite in line with the deductions drawn several years ago and presented in the paper by Mr. Lilliequist and myself on inclusion formation.* We asserted at that time that the inclusions were in solution in the steel and precipitated out only during the cooling and solidification. The evidence seemed very clear, although the explanation that we gave was far from complete. These authors have filled in a great many of these gaps.

R. A. BULL:[2] In paragraph 74, it is stated that, "The average content of sulphur which can be obtained at the end of the reduction period with a good desulphurizing slag in the basic electric furnace is 0.10 per cent sulphur. The sulphur content of acid steel is on the whole much larger (0.020 per cent and more)." Of course, in American practice the sulphur content is much higher than that, whether the furnace is open hearth or electric. Then the authors state: "It is thus evident that the proportion of manganese sulphide in nonmetallic inclusions formed in acid steel will be largely different from that in basic electric steel, which will result in a different behavior of nonmetallic inclusions." It is this last sentence on which I wonder whether Mr. Sims can throw any light, considering the fact that he and Mr. Lilliequist have undoubtedly given a lot of constructive study to the behavior, shape, and inter-relationships of these nonmetallic inclusions.

MR. SIMS: I believe the author is referring to the illustration given in Fig. 10, where the gas evolution varied with the sulphur content of the steel; in other words, in acid steel, there will always be a much higher content of sulphur and there will be no chance for sulphur elimination, and therefore this effect of decreasing sulphur will not be felt. In the basic electric, the sulphur will be constantly diminishing during

*Sims, C. E., and Lilliequist, G. A., *"Inclusions—Their Effect, Solubility and Control in Cast Steel."* TRANS. A.I.M.E. (1932).

[2]Consultant on Steel Castings, Chicago.

possess a complete knowledge of the more scientific details of its processes.

Specifications for steel castings are perpetually increasing in severity. The field of application of steel castings will be in direct proportion to the success with which the product meets this increased severity of demand.

Many of us have known for a considerable time of the remarkable effect of non-metallic inclusions, both in their degree of occurrence, constitution, size and shape, and we know that small as these inclusions are, they exert a controlling influence upon structural formation and therefore upon physical test properties. The present paper, therefore, is extremely opportune, and should be of interest to steel founders.

As electric furnace production in this country for steel foundry purposes is almost entirely of the acid type, it would have been still more interesting had this method of manufacture been included in the present paper. It has been my experience that the occurrence of non-metallic inclusions and their control are not necessarily the same in acid electric and acid open hearth methods of manufacture. This may be due to a variety of causes. The function of time is not negligible, nor is the possible effect of localized high temperature in the neighborhood of the arc upon slag constitution.

To the steel founder, the value of the scientific reasonings in the paper under discussion lies in the degree to which they can be applied to actual steelmaking practice in the foundry. Beginning with paragraph 32 under the heading of "Reduction of Silicon," for instance, is a scientific reasoning of a steelmaking fact which has been observed for a very long time. It is well known that the crucible steelmakers of old times in Sheffield, England, fully understood from the practical viewpoint the process of increasing silicon content in a crucible of molten steel when this steel contained appreciable quantities of manganese, the silicon in this case, of course, being very largely derived at the expense of the containing pot. In acid electric practice, the reduction of silicon into the bath is quite an important practical operating point, and its understanding and control exerts a powerful influence on the physical properties later to be obtained in the resulting metal.

The explanation given (beginning with paragraph 45) of gas evolution from solidifying steel, also should be of very serious interest to a steel foundryman. Under paragraph 51 is given an explanation of acid steel in small test molds in relation to gas evolution, and it may be that a careful study of this paragraph will set the minds of many of our steel founding friends to work along new lines in considering the causes and control of certain types of porosity in steel castings.

The section on the evolution of gas in basic electric steel will, I am afraid, not be of so great a practical interest to American steel founders as would have been the case had it been on acid electric steel. For a good many sound reasons, this latter process has obtained almost a monopoly in the steel founding industry in this country, where electric melting is operated, and of course the physical chemistry is entirely different in the two processes.

I would like, finally to emphasize to my steelmaking colleagues, that

I am sure that the value of this paper will only become available as it is more carefully and rather laboriously studied. Such papers are necessarily complicated, and their value cannot be seen by a casual reading. I should like to congratulate the authors on a clearly stated series of deductions and explanations on a very interesting subject.

MR. SIMS: I think the principles expounded by the authors are worthy of very careful consideration and study. The example given in Fig. 1, where the silicon is reduced from the slag, serves its purpose very well in illustrating equilibrium relations, but I do not think it should be recommended as a matter of practice. There are pitfalls in the way of operating in this manner where silicon is reduced from the slag. One may get a steel that will solidify without any harmful degree of evolution of gas in an ingot mold, but my own experience leads me to believe that such practice will lead to steel that would be very susceptible to gas evolution.

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the reducing period, and the point will be reached with the lower sulphur where you will get the fusible inclusion which is more reactive and more likely to cause gas evolution.

MAJ. BULL: What I had in mind was whether you could make the inclusions behave themselves decently, so to speak, in acid open hearth steel as well as you have indicated they might be treated in your paper before the A.I.M.E.? In other words, does the difference in sulphur seem to be a controllable factor?

MR. SIMS: Yes, I think the influence of inclusions on the physical properties of steel is greatly affected by the quantity of sulphide present and the manner in which it precipitates. Of course, that is a little aside from anything the authors refer to.

There is one salient point in this paper that puzzles me. It is the assertion that as the metal cools down towards the freezing temperature, inclusions precipitate out and the iron oxide in these inclusions then reacts with the carbon to form carbon monoxide. It seems to me that there would be reactions going both ways from equilibrium. For instance, let us assume, as the authors do, that when liquid steel is taken out of the furnace in a ladle, that it contains only a small excess of iron oxide over that which will be in equilibrium with the carbon content of the metal. The rapid cooling of the metal upsets the silicon-manganese-oxygen equilibrium and causes the precipitation of silicate inclusions. Though unaffected by temperature, this depletion of oxygen to form silicates, displaces the carbon-oxygen equilibrium and produces an excess of carbon.

Therefore, as precipitation of inclusions continues, the chance for the reaction $FeO + C \leftrightarrows Fe + CO$ to take place grows poorer. Even though there would be a tendency for reaction at the surface of the inclusions due to concentration of the FeO, the intimate contact of the low oxygen steel would reverse the reaction.

The following seems a more logical explanation. When the liquid steel is taken from the furnace in a ladle there is an excess of oxygen over the carbon-oxygen equilibrium. The reaction is in a static condition because the high surface tension of the steel presents enough resistance to bubble formation beneath the surface to prevent the formation of CO. When precipitation of silicates takes place, it still leaves an excess of oxygen and provides internal surfaces on which the CO bubbles can form.

A. C. JONES[3]: As I understand Mr. Sims' resumé of it, isn't it reasonable to expect that if FeO becomes concentrated, with the separation of the manganese silicate inclusions, that from a steel casting point of view it would be highly desirable to keep the carbon low so that carbon would not be readily available for the reaction.

$$FeO + C \leftrightarrows Fe + CO$$

Several years ago I purposely made an experimental heat of steel in an Ajax induction furnace of the composition 0.04 per cent carbon, 0.50 per cent silicon, and 0.03 per cent manganese and poured the metal into green sand molds to make castings from a pattern purposely designed to develop pinhole porosity. No aluminum was employed. The castings

[3] Lebanon Steel Foundry, Lebanon, Pa.

were free from any indication of porosity, whereas castings from a heat of 0.25 per cent carbon with normal silicon and manganese poured in similar molds, were quite porous. This of course is a slightly different condition with respect to equilibria, in that the break-up of steam from the mold into hydrogen and oxygen has resulted in an excess of FeO in the steel, which in the case of the normal carbon content, produced CO that resulted in porosity. This particular experiment also proved to me that this porosity (in most cases) is not the direct effect of the physical impingement of mold gases, as advanced by some foundrymen, but develops from within the metal as the result of the above stated reaction between C and FeO.

MR. SIMS: I believe the explanation is given in Fig. 5, page 14. There the authors show plainly that the lower the carbon the lower is the minimum silicon and manganese necessary to prevent evolution of CO.

MR. JONES: I understood the concentration of iron oxide was greater in localized points and therefore the reaction would be set up in a freezing steel with that reaction in carbon.

MR. SIMS: It does show that the danger is much greater in high carbon steel than in low carbon steel.

# The Effect of Elevated Temperatures on the Strength and Dimensional Stability of Certain Aluminum Alloys Used in Aircraft

By Richard R. Kennedy,* Dayton, O.

**Abstract**

*Several investigators have published data on the tensile strength of aluminum alloys obtained from short time tests at elevated temperatures. The effect of prolonged exposure to these temperatures has not been so thoroughly investigated. The importance of such data is indicated by the changes which occur during the fabrication and service life of castings for aircraft engines.*

*A series of experiments were conducted on four aluminum alloys to determine the effect on the dimensional changes and physical properties of exposure periods up to 192 hours at temperatures within the range of 350-550 degrees Fahr. The copper-nickel-magnesium alloys (X and Y) in the heat treated condition were least affected. The ¼ per cent copper—0.7 per cent silicon alloy showed considerable permanent growth after reheating. The 5 per cent silicon—1.25 per cent copper alloy had the lowest tensile strength and hardness of the alloys investigated.*

1. The increase in performance of aircraft engines in the past few years has been due to a considerable extent to the improvement of materials used in their construction. Since at least 50 per cent of the weight of the engine is in the form of aluminum alloy castings or forgings, any improvement in the properties of these alloys can be used advantageously by the engine designer.

2. Engine parts such as cylinder heads and pistons, which are exposed to elevated temperatures in service, suffer a loss in strength at operating temperatures and may be annealed partially, so that the strength of the parts is impaired permanently even after cooling to room temperature. Further, some aluminum alloys are sub-

* Associate Metallurgist, War Department, Air Corps, Materiel Division, Wright Field.

Note: This paper was presented at one of the sessions on Nonferrous Founding at the 1934 Convention of the A.F.A.

ject to permanent growth when exposed to elevated temperatures. In some cases, the amount of growth is sufficient to render the parts worthless.

3. A number of cast aluminum alloy cylinder heads have been examined after they have been in service for varying periods. It has been found in every instance that the strength of the casting is much lower than that of the original alloy. While it is known that the tensile strength of test specimens machined from castings is, in general, lower than that of cast to size test specimens poured

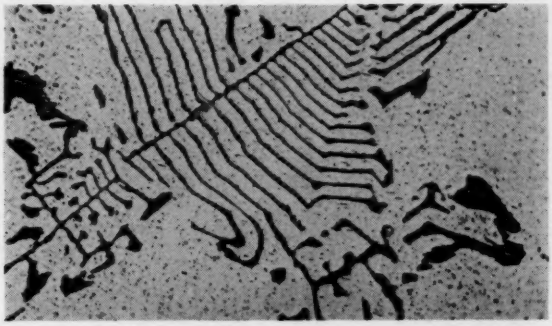

FIG. 1—PRECIPITATE OF Cu $Al_2$ PARTICLES IN SPECIMEN FROM ALUMINUM ALLOY CYLINDER HEAD CASTING. PRECIPITATION PROBABLY WAS CAUSED BY HEATING IN THE ANNEALING RANGE IN SERVICE. ETCHED IN 20 PER CENT NITRIC ACID. MAGNIFICATION, 500X.

from the same alloy, the tensile strength of specimens machined from these cylinder heads was too low to be explained by this phenomenon.[1]

4. Metallographic specimens from cylinder-heads cast from heat treated aluminum-copper alloys have been examined in which the particles of Cu $Al_2$ precipitate had grown to such size as to be detectable readily under the microscope. Fig. 1 shows a specimen which evidently had been heated in the annealing range in service thus causing the particles of precipitate to grow to microscopic size.

5. In examining a cylinder-head, tensile specimens are taken from various portions of the casting as shown in Fig. 2. These specimens are machined to size and the tensile properties are determined. Results of tests on three cylinder-heads of similar design cast from the same type of aluminum alloy are given in Table

[1] Dix, E. H. and Lyon, A. J., *Comparative Tensile Properties of Copper, Silicon, Aluminum and Other Aluminum Alloys as Obtained on Separately Cast Test Specimens and Specimens Cut from a Crankcase Casting*, J. Inst. Metals, vol. 32, p. 27, 1924.

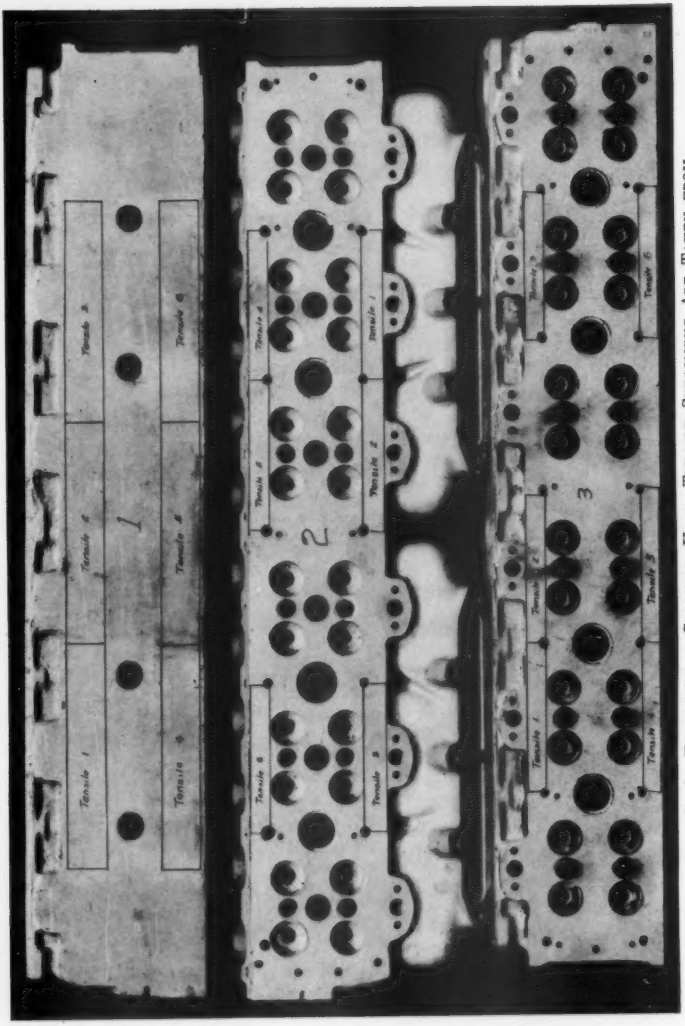


FIG. 2—IN EXAMINING A CYLINDER HEAD, TENSILE SPECIMENS ARE TAKEN FROM VARIOUS PORTIONS OF THE CASTING AS SHOWN.

1. The tensile strength of cast to size test bars of this alloy, after heating to 980 degrees Fahr. for 16 hours, quenching in cold water and aging at 440 degrees Fahr. for 8 hours, is approximately 35,000 lbs. per square inch. The progressive loss of strength of these cylinder-heads with increasing time in service can be seen in Table 1. Cylinder-head No. 1 had not been in service; cylinder-head No. 2 had 10 hours' service, and cylinder-head No. 3 had 100 hours' service.

6. The loss of strength may be attributed to two factors:

**Table 1**

PHYSICAL PROPERTIES OF SPECIMENS FROM CAST ALUMINUM ALLOY CYLINDER HEADS

| Cylinder Head No. | 1 | 2 | 3 |
|---|---|---|---|
| Hours in Service | None | 10 | 100 |
| Tensile Strength, Spec. 1, lbs./sq. in. | 23,120 | 20,980 | 18,950 |
| Tensile Strength, Spec. 2, lbs./sq. in. | 28,610 | 20,950 | 19,040 |
| Tensile Strength, Spec. 3, lbs./sq. in. | 27,080 | 18,360 | 18,430 |
| Tensile Strength, Spec. 4, lbs./sq. in. | 25,940 | 22,810 | 19,770 |
| Tensile Strength, Spec. 5, lbs./sq. in. | 24,010 | 19,030 | 19,410 |
| Tensile Strength, Spec. 6, lbs./sq. in. | 11,520 [1] | 20,860 | 17,250 |
| Tensile Strength, Average | 25,740 | 20,490 | 18,800 |
| Proportional Limit, lbs./sq. in. | 17,550 | 10,000 | 7,330 |
| Brinell Hardness, Average [2] | 83 | 58 | 47 |
| Composition | | | |
| Silicon, Per Cent | 5.33 | 5.58 | 5.07 |
| Copper, Per Cent | 1.02 | 0.84 | 1.02 |
| Iron, Per Cent | 0.51 | 0.43 | 0.21 |
| Magnesium, Per Cent | 0.59 | 0.32 | 0.36 |
| Aluminum, Per Cent | Remainder | Remainder | Remainder |

[1] Specimen contained inclusion. Excluded from average.
[2] 500 Kg. load.

(1)—The "normalizing" treatment to which the castings are subjected after heat treatment, in which the castings are heated to 500-550 degrees Fahr. for 2 to 5 hours for removing any tendency toward permanent growth and for shrinking in inserts.

(2)—The annealing effect of operating temperatures on the casting.

7. The exact temperature to which these parts are heated in service is not known always but temperature measurements taken during block tests of engines indicate a range between 250 and

550 degrees Fahr. for *crankcases* and cylinder-heads, the lower portion of the range for liquid-cooled and the upper portion for air-cooled engines. The investigation described in this paper was conducted to determine the casting shrinkage of several aluminum alloys used in aircraft, also the effect of heat treatment and of exposure to temperatures in the operating range (350 to 550 degrees Fahr.) on the strength and dimensional stability of these alloys.

## ALLOYS USED IN INVESTIGATION

8. The following alloys were used in the investigation.

Alloy 1—Aluminum-copper alloy containing 4 to 5 per cent copper with smaller amounts of silicon and iron.

Alloy 2—X alloy, heat treated. An aluminum-copper-nickel-magnesium-silicon alloy developed by Capt. A. J. Lyon, U. S. Army Air Corps.[2]

Alloy 3—X alloy, "as cast."

Alloy 4—Y alloy, heat treated. Contains 4 per cent copper, 2 per cent nickel, 1½ per cent magnesium and remainder aluminum.

Alloy 5—Y alloy, "as cast."

Alloy 6—Aluminum-silicon-copper-magnesium alloy, recently developed.

9. These aluminum alloys generally are used in the heat treated condition but in cooling from the liquid state, certain of the soluble constituents are retained in solid solution, even when the rate of cooling is comparatively slow as in a green sand mold. On reheating to temperatures below the annealing range, these constituents should be precipitated, thus increasing the strength and hardness of the alloys. To determine the improvement in tensile strength which takes place in "as cast" alloys after exposure to elevated temperatures, *X* and *Y* alloys in the "as cast" condition were included in the investigation.

## DESCRIBES MELTING PRACTICE

10. In making the alloys, virgin aluminum ingot and the necessary intermediate alloys were charged into a 350-pound iron pot, gas fired furnace. When the metal was melted and thoroughly mixed, it was poured into ingot molds. Magnesium, when required, was added just before pouring. A sufficient amount of

[2] Lyon, A. J., *Aluminum Alloys for Aircraft — Engine Pistons and Cylinder Heads*, Aeronautical Eng. (A.S.M.E. Trans.) vol. 2, pp. 257-269, 1930.

each alloy was made so that all test castings could be poured from the same lot of ingot metal. The composition of the alloys used is given in Table 2.

11. Test castings were poured from metal which was melted in clay graphite crucibles. Each charge consisted of 50 per cent ingot metal and 50 per cent gates and sprues from the same lot of ingot metal. When the metal had reached a temperature at or slightly above the pouring temperature, the crucible was withdrawn from the furnace and the temperature of the metal was determined using a closed end thermocouple and a potentiometer. If the metal was too hot it was cooled with cast iron chills to the pouring temperature which was 1250 degrees Fahr. in all cases.

**Table 2**

CHEMICAL COMPOSITION OF ALLOYS USED

| Element | Alloy 1 | Alloys 2 and 3 | Alloys 4 and 5 | Alloy 6 |
|---|---|---|---|---|
| Copper, Per Cent..... | 4.16 | 3.59 | 4.05 | 1.26 |
| Silicon, Per Cent..... | 0.59 | 0.63 | 0.23 | 4.60 |
| Nickel, Per Cent..... | .... | 0.59 | 1.99 | .... |
| Magnesium, Per Cent..... | .... | 0.73 | 1.62 | 0.55 |
| Iron, Per Cent ..... | 0.52 | 1.39 | 0.55 | 0.55 |
| Aluminum, Per Cent..... | Remainder | Remainder | Remainder | Remainder |

12. The Air Corps standard tension bar was used for the determination of tensile properties of the alloys. These bars are cast three in a mold and have a 2-in. gage length and a 0.505-in. diameter in the gage section. They are tested without machining.

13. A bar 12 inches long and 1 inch square was used both for the determination of casting shrinkage and for growth at elevated temperatures. All test castings were poured in green sand molds.

14. Flask and pattern equipment used in casting the shrinkage bars is shown in Fig. 3. The flasks were cast from an aluminum alloy, while the templates, nuts and taper pins were machined from corrosion resistant steel. The distance between templates was approximately 12 inches and was determined accurately at frequent intervals and appropriate corrections were made.

15. The length of the bars was determined on the bench micrometer shown in Fig. 4. The bar *a* was placed on supports *b-b* and spindles *c-c* were brought against the ends of the bar with sufficient pressure to bring the bubble of spirit level *e* between the

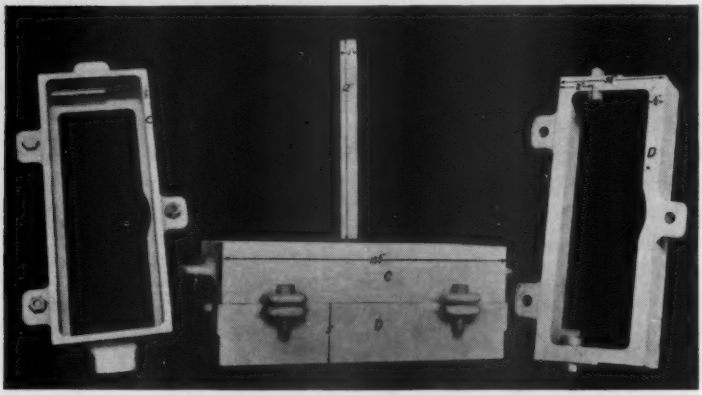

FIG. 3—FLASKS AND PATTERN EQUIPMENT USED IN CASTING BARS FOR DETERMINATION OF SHRINKAGE.

hair lines. The relative length of the bars could then be read on vernier *d*. As the micrometer read only relative length, it was necessary to set the instrument against a master bar, the length of which was accurately known. A cast aluminum alloy bar was used for this purpose. The bar was annealed at 650 degrees Fahr. for 8 hours after which it was machined all over and the ends were ground parallel. The length then was determined in a Zeiss Universal Measuring Microscope to an accuracy of .00001 inch.

16. The shrinkage bars were measured in the as cast condi-

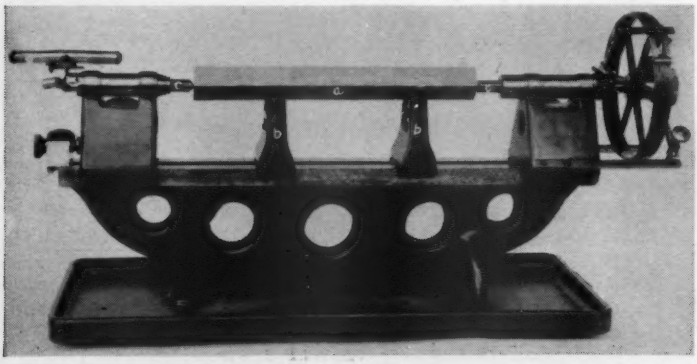

FIG. 4—THE LENGTH OF THE SHRINKAGE BARS WAS MEASURED IN THE AS CAST CONDITION, AFTER SOLUTION HEAT TREATMENT AND AFTER AGING TREATMENT, IN A BENCH MICROMETER OF THE TYPE SHOWN.

tion, after solution heat treatment and after aging treatment. Ends of the bars were then machined parallel, so that more precise measurements might be made to determine changes which took place in the elevated temperature tests. All results were corrected to a length of 12 inches.

17. The solution heat treatment of the shrinkage bars and tension bars was carried out in a box type electric furnace whose temperature was controlled to within ± 10 degrees Fahr. All

**Table 3**

HEAT TREATMENT USED FOR TEST CASTINGS

| Alloy No. | Solution Treatment | | Aging Treatment | |
|---|---|---|---|---|
| | Temperature— Degrees Fahr. | Time— Hours | Temperature— Degrees Fahr. | Time— Hours |
| 1 | 960 | 24 | 300 | 2 |
| 2 | 960 | 16 | 375 | 5 |
| 4 | 950 | 16 | 375 | 5 |
| 6 | 980 | 16 | 440 | 8 |

castings were quenched in cold water at the conclusion of the solution treatment and were aged in an electric oven or a Homo furnace. The details of heat treatment are given in Table 3.

18. To determine the effect of elevated temperatures on the properties of the alloys, tension and shrinkage bars from all alloys were heated to 350 degrees Fahr. Tension bars were withdrawn from the furnace at periods varying from 3 to 192 hours. The shrinkage bars were withdrawn from the furnace, cooled in air, measured on the bench micrometer and replaced in the furnace at intervals until the total time of heating amounted to 192 hours. Similar heating tests were run on all alloys at 400, 475 and 550 degrees Fahr.

19. Three shrinkage bars were used for each alloy at each temperature and not less than three tension bars were tested for each period of heating.

20. After the tension bars had cooled to room temperature, they were tested in a 20,000-pound Amsler tensile machine and the ultimate tensile strength and elongation in 2 inches was determined. Brinell hardness was determined on the grips of the tension bars using a 500 kg. load.

21. The method used for the determination of casting shrinkage has been used by other investigators to determine the shrinkage of gray iron and many of the non-ferrous alloys. Anderson[3]

[3] Anderson, R. J., *Linear Contraction and Shrinkage of a Series of Light Aluminum Alloys*, TRANSACTIONS, A.F.A., vol. 31, pp. 392-466, 1923.

has reported the shrinkage of a large number of aluminum alloys using apparatus quite similar to that employed in the present investigation.

22. Since the distance between templates in the shrinkage bar mold is 12 inches, the amount by which the bars, when cold, are shorter than 12 inches is considered to be the casting shrinkage of the alloy under investigation.

23. Results of shrinkage determinations given in Table 4 represent averages of measurements made on 12 bars of alloys 1 and 6, and 24 bars of alloys 2 and 4. Alloy 1 showed the greatest amount of casting shrinkage and alloy 6 the least, due to its high silicon content.

24. The dimensional changes which took place as a result of solution and precipitation heat treatment are also shown in Table 4. These changes were quite small when compared with the casting shrinkage. They were greatest in alloy 1 and least in alloy 4. Alloys 3 and 5, *X* and *Y* alloys in the as cast condition, are not included in this table.

**Table 4**

CASTING SHRINKAGE AND DIMENSIONAL CHANGE OCCURRING IN HEAT TREATMENT

| Alloy No. | Casting Shrinkage— in. per ft. | Change on Quenching— in. per ft. | Change on Aging— in. per ft. |
|---|---|---|---|
| 1 | 0.185 | —0.0040 | —0.0012 |
| 2 | 0.184 | —0.0035 | —0.0006 |
| 4 | 0.172 | —0.0004 | —0.0004 |
| 6 | 0.164 | +0.0010 | —0.0001 |

25. The tensile strength, elongation and hardness of the alloys, as cast, after the solution treatment and after aging are shown in Table 5. Alloy 3, *X* alloy in the as cast condition, had the highest tensile strength of the as cast alloys, while alloy 2, the same alloy heat treated, showed the highest strength among the alloys after heat treatment. Alloys 1 and 6 had approximately the same tensile strength after heat treatment, but alloy 1 had better ductility.

26. The results of tests conducted after heating to elevated temperatures are given in Tables 6 and 7, and Figs. 5 to 8, while the original physical properties of the alloys before reheating are

**Table 5**

PHYSICAL PROPERTIES OF CAST ALUMINUM ALLOYS AS CAST AND AFTER HEAT TREATMENT

| Alloy No. | As Cast | | | As Quenched | | | As Aged | | |
|---|---|---|---|---|---|---|---|---|---|
| | Tensile Strength Lb./ sq. in. | Elong. in 2 in. per cent | Brin. Hard-ness | Tensile Strength Lb./ sq. in. | Elong. in 2 in. per cent | Brin. Hard-ness | Tensile Strength Lb./ sq. in. | Elong. in 2 in. per cent | Brin. Hard-ness |
| 1 | 21,140 | 3.5 | 55 | 31,910 | 8.5 | 68 | 36,390 | 6.8 | 74 |
| 2 | ..... | ... | .. | 31,080 | 6.0 | 72 | 47,340 | .5 | 122 |
| 3 | 30,820 | 1.5 | 82 | ..... | ... | .. | ..... | ... | ... |
| 4 | ..... | ... | .. | 29,770 | 2.5 | 81 | 41,250 | .5 | 114 |
| 5 | 28,860 | .5 | 90 | ..... | ... | .. | ..... | ... | ... |
| 6 | 24,160 | 1.5 | 71 | 26,540 | 4.5 | 77 | 35,250 | 1.0 | 92 |

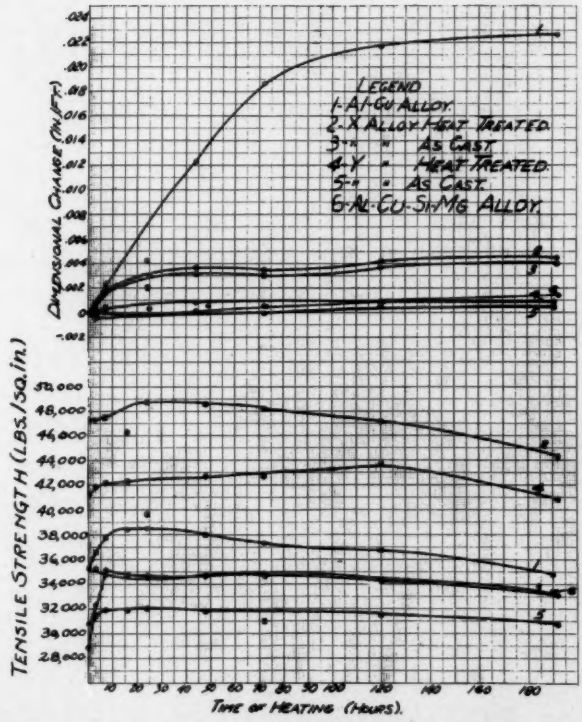


FIG. 5—CURVES SHOWING THE DIMENSIONAL CHANGES AND TENSILE STRENGTHS OF BARS AFTER HEATING TO 350 DEGREES FAHR. FOR VARIOUS TIME INTERVALS.

## Table 6

### PHYSICAL PROPERTIES OF ALUMINUM ALLOYS AFTER HEATING FOR VARIOUS PERIODS

| Alloy No. | Period Heated—Hours | Heated to 350 Degrees Fahrenheit: Tensile Strength—Lb./sq. in. | Elong. in 2in.—per cent | Brinell Hardness | Heated to 400 Degrees Fahrenheit: Tensile Strength—Lb./sq. in. | Elong. in 2 in.—per cent | Brinell Hardness | Heated to 475 Degrees Fahrenheit*: Tensile Strength—Lb./sq. in. | Elong. in 2 in.—per cent | Brinell Hardness | Heated to 550 Degrees Fahrenheit: Tensile Strength—Lb./sq. in. | Elong. in 2 in.—per cent | Brinell Hardness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 36,570 | 2.9 | 90 | 36,540 | 2.5 | 89 | 33,980 | 2.7 | 76 | 29,420 | 5.7 | 66 |
| | 7 | 37,780 | 3.0 | 86 | 36,140 | 2.5 | 85 | 34,380 | 2.5 | 78 | 27,910 | 3.9 | 63 |
| | 16 | 38,420 | 2.5 | 90 | 36,330 | 2.2 | 85 | 32,710 | 2.5 | 73 | 27,360 | 3.5 | 62 |
| | 24 | 38,450 | 2.0 | 93 | 35,180 | 2.0 | 78 | 30,690 | 3.0 | 65 | 27,350 | 4.2 | 51 |
| | 48 | 39,120 | 1.5 | 95 | 34,460 | 2.0 | 76 | 29,370 | 3.5 | 63 | 26,450 | 4.0 | 57 |
| | 72 | 37,360 | 2.0 | 84 | 34,000 | 2.3 | 76 | 29,200 | 3.0 | 65 | 26,070 | 4.7 | 55 |
| | 120 | 36,760 | 2.2 | 87 | 33,040 | 2.3 | 72 | 28,800 | 3.0 | 61 | 24,860 | 5.5 | 53 |
| | 192 | 34,800 | 1.7 | 83 | 32,110 | 2.8 | 70 | 28,400 | 4.0 | 61 | 24,540 | 4.8 | 52 |
| 2 | 3 | 47,300 | 0.5 | 121 | 48,490 | 0.5 | 124 | 44,500 | 0.5 | 115 | 32,210 | 1.5 | 83 |
| | 7 | 47,590 | 0.5 | 121 | 48,100 | 0.5 | 121 | 43,290 | 0.5 | 114 | 29,990 | 2.6 | 73 |
| | 16 | 46,290 | 0.5 | 125 | 47,180 | 0.5 | 116 | 40,840 | 0.5 | 103 | 29,260 | 2.6 | 70 |
| | 24 | 48,710 | 0.5 | 128 | 46,040 | 0.5 | 109 | 35,450 | 0.5 | 91 | 27,210 | 2.5 | 66 |
| | 48 | 48,460 | 0.5 | 133 | 43,930 | 0.5 | 104 | 31,310 | 0.5 | 79 | 25,920 | 2.5 | 66 |
| | 72 | 48,180 | 0.5 | 117 | 43,560 | 0.5 | 110 | 30,400 | 1.7 | 81 | 25,880 | 2.5 | 60 |
| | 120 | 47,140 | 0.5 | 124 | 43,470 | 0.5 | 99 | 28,770 | 2.0 | 68 | 24,760 | 2.5 | 58 |
| | 192 | 44,240 | 0.5 | 117 | 41,590 | 0.5 | 102 | 27,660 | 2.0 | 71 | 25,030 | 3.7 | 57 |
| 3 | 3 | 32,330 | 0.5 | 92 | 33,000 | 0.5 | 98 | 33,080 | 0.5 | 92 | 28,540 | 0.8 | 78 |
| | 7 | 35,090 | 0.5 | 100 | 34,780 | 0.5 | 92 | 32,510 | 0.5 | 89 | 27,570 | 1.3 | 76 |
| | 16 | 34,760 | 0.5 | 96 | 34,360 | 0.5 | 92 | 32,950 | 0.5 | 82 | 26,920 | 1.8 | 72 |
| | 24 | 34,710 | 0.5 | 98 | 32,350 | 0.5 | 88 | 32,140 | 0.5 | 87 | 26,850 | 2.0 | 69 |
| | 48 | 34,650 | 0.5 | 103 | 33,210 | 1.0 | 91 | 29,290 | 0.7 | 77 | 25,950 | 1.7 | 67 |
| | 72 | 34,720 | 0.5 | 98 | 32,220 | 0.5 | 85 | 27,840 | 0.6 | 76 | 25,580 | 1.7 | 65 |
| | 120 | 34,180 | 0.5 | 96 | 31,680 | 0.7 | 81 | 28,670 | 0.8 | 75 | 23,980 | 2.0 | 62 |
| | 192 | 33,040 | 0.5 | 92 | 31,630 | 0.5 | 88 | 27,270 | 0.8 | 78 | 22,710 | 2.0 | 60 |

**Table 6**
*(Continued)*

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 3 | 41,910 | 0.5 | 124 | 41,950 | 0.5 | 124 | 40,210 | 0.5 | 106 | 35,180 | 0.8 | 96 |
| | 7 | 42,170 | 0.5 | 115 | 41,360 | 0.5 | 124 | 39,760 | 0.5 | 106 | 31,920 | 1.5 | 89 |
| | 16 | 42,320 | 0.5 | 118 | 40,810 | 0.5 | 108 | 38,330 | 0.5 | 102 | 31,050 | 1.2 | 83 |
| | 24 | 39,630 | 0.5 | 125 | 39,990 | 0.5 | 111 | 37,270 | 0.5 | 98 | 29,270 | 1.6 | 79 |
| | 48 | 42,660 | 0.5 | 125 | 39,310 | 0.7 | 106 | 35,130 | 0.5 | 88 | 26,890 | 1.5 | 72 |
| | 72 | 42,700 | 0.5 | 120 | 38,800 | 0.5 | 110 | 35,010 | 0.5 | 93 | 26,280 | 1.5 | 70 |
| | 120 | 43,630 | 0.5 | 120 | 38,990 | 0.5 | 98 | 32,860 | 0.5 | 86 | 25,060 | 1.8 | 67 |
| | 192 | 40,850 | 0.5 | 107 | 38,470 | 0.5 | 97 | 32,660 | 1.0 | 89 | 24,350 | 1.7 | 65 |
| 5 | 3 | 31,520 | 0.5 | 100 | 31,120 | 0.5 | 98 | 30,530 | 0.5 | 92 | 26,950 | 0.5 | 85 |
| | 7 | 31,960 | 0.5 | 101 | 30,720 | 0.5 | 106 | 29,990 | 0.5 | 92 | 25,830 | 0.8 | 78 |
| | 16 | 31,910 | 0.5 | 104 | 30,780 | 0.5 | 97 | 29,800 | 0.5 | 88 | 25,310 | 1.0 | 77 |
| | 24 | 32,050 | 0.5 | 102 | 30,750 | 0.5 | 92 | 29,260 | 0.5 | 87 | 24,850 | 0.5 | 75 |
| | 48 | 31,780 | 0.5 | 104 | 30,670 | 0.5 | 90 | 28,200 | 0.5 | 82 | 24,030 | 1.0 | 70 |
| | 72 | 30,950 | 0.5 | 95 | 30,690 | 0.5 | 86 | 28,500 | 0.5 | 86 | 23,570 | 1.0 | 70 |
| | 120 | 31,530 | 0.5 | 107 | 29,790 | 0.5 | 82 | 27,850 | 0.5 | 82 | 23,370 | 1.5 | 66 |
| | 192 | 30,730 | 0.5 | 95 | 29,930 | 0.5 | 87 | 27,130 | 1.0 | 82 | 23,030 | 1.5 | 63 |
| 6 | 3 | 35,250 | 0.5 | 88 | 34,760 | 0.8 | 91 | 29,880 | 1.5 | 77 | 24,270 | 1.0 | 61 |
| | 7 | 34,690 | 0.5 | 82 | 34,150 | 1.0 | 92 | 29,260 | 1.2 | 74 | 23,710 | 2.2 | 57 |
| | 16 | 34,800 | 0.5 | 88 | 33,500 | 0.5 | 90 | 27,700 | 1.2 | 70 | 23,260 | 2.5 | 53 |
| | 24 | 34,530 | 0.5 | 86 | 32,830 | 0.5 | 89 | 27,090 | 1.2 | 66 | 21,440 | 2.5 | 50 |
| | 48 | 34,610 | 0.5 | 87 | 32,360 | 0.8 | 84 | 25,310 | 2.0 | 60 | 21,160 | 3.2 | 51 |
| | 72 | 34,830 | 0.5 | 86 | 32,070 | 0.7 | 84 | 24,740 | 2.0 | 53 | 19,480 | 2.7 | 47 |
| | 120 | 34,330 | 0.5 | 87 | 30,790 | 1.0 | 80 | 23,150 | 1.5 | 55 | 20,910 | 4.2 | 48 |
| | 192 | 32,990 | 0.5 | 74 | 28,910 | 0.8 | 75 | 22,410 | 2.3 | 50 | 20,560 | 4.0 | 46 |

*Maximum time of heating at 475° F. was 171 hours instead of 192 hours.

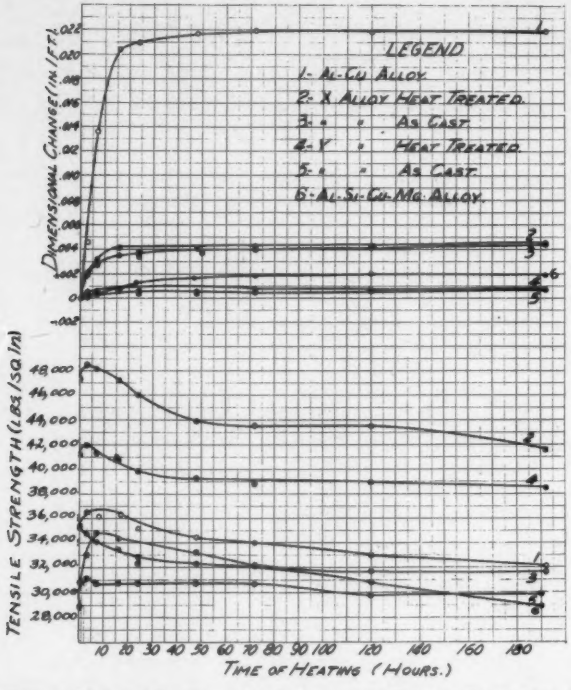


FIG. 6—CURVES SHOWING DIMENSIONAL CHANGES AND TENSILE STRENGTHS OF BARS AFTER HEATING TO 400 DEGREES FAHR. FOR VARIOUS TIME INTERVALS.

given in Table 5. Results given in Tables 6 and 7 and Figs. 5 to 8 represent the properties of the alloys determined at *room temperature*, after the alloys were heated to elevated temperatures for various periods. These results bear no direct relation to the properties of the alloys while actually at the elevated temperatures, but represent changes which took place as a result of heating.

27. None of the alloys showed any appreciable loss of strength after reheating to 350 degrees Fahr., in fact, all alloys, except alloy 6, increased in strength after the shorter periods of heating. While alloys 3 and 5 showed marked increases in tensile strength, alloys 2 and 4, the same alloys in the heat treated condition, were much stronger after reheating to this temperature. The elongation of alloy 1, the only alloy of the series which possessed any appreciable amount of ductility originally, dropped off

sharply after even short periods of heating. With the exception of alloy 6, the Brinell hardness increased and then dropped off as the time of heating was extended.

28. Alloy 1 showed the greatest amount of permanent growth after reheating to 350 degrees Fahr. The total increase in length amounted to 0.19 per cent. *X* alloy bars, alloys 2 and 3, increased slightly in length, while the growth in the other alloys was negligible in amount.

29. After reheating to 400 degrees Fahr. for the longer periods, all alloys showed greater losses of strength than after reheating to 350 degrees Fahr. for the same periods, although in no case can the loss of strength be termed serious. Alloys 2 and 4 had the highest tensile strength of the alloys tested at that temperature. However, it is interesting to note that alloys 3 and 5 were stronger at the conclusion of the 192-hour period of heating than in the as cast condition. Alloy 1 again showed the greatest amount of permanent growth while only small changes were observed in the other alloys.

### ALLOYS WEAKEN AT HIGHER TEMPERATURES

30. All alloys showed the weakening and softening influence of the higher temperature after reheating at 475 degrees Fahr. Up to 16 hours, alloy 2 appears to have superior properties, but somewhere between 18 and 24 hours of heating, there appears to be a sudden drop both in tensile strength and Brinell values. Alloy 4, although not having as great tensile strength as alloy 2, after 3 hours of heating, shows to advantage after 172 hours of heating, since the decrease in tensile strength with increasing heating time is not as great in alloy 4 as in alloy 2. The same is true for Brinell hardness. Alloy 6 showed little dimensional change when heated for the full 192-hour period. Tests on the other alloys were concluded at 48 hours, but the amount of dimensional change at that point was comparable with that observed at lower temperatures.

31. After reheating to 550 degrees Fahr., all alloys showed large losses in tensile strength and hardness. Alloys 1, 2 and 4 showed approximately the same tensile strength at the conclusion of the full heating period. The amount of permanent growth which took place at 550 degrees was, in general, less than at the lower temperatures.

32. In general, tensile strength and hardness increased for

## Table 7

### DIMENSIONAL CHANGES IN ALUMINUM ALLOYS AFTER HEATING TO VARIOUS TEMPERATURES

| Alloy No. | Heated to 350 Degrees Fahrenheit | | Heated to 400 Degrees Fahrenheit | | Heated to 475 Degrees Fahrenheit | | Heated to 550 Degrees Fahrenheit | |
|---|---|---|---|---|---|---|---|---|
| | Period Heated—Hours | Dimensional Change—in./ft. | Period Heated—Hours | Dimensional Change—in./ft. | Period Heated—Hours | Dimensional Change—in./ft. | Period Heated—Hours | Dimensional Change—in./ft. |
| 1 | 3 | +0.0008 | 3 | +0.0046 | 3 | +0.0115 | 3 | +0.0185 |
| | 7 | +0.0023 | 7 | +0.0136 | 7 | +0.0189 | 7 | +0.0188 |
| | ... | ..... | 16 | +0.0204 | 16 | +0.0208 | 16 | +0.0170 |
| | 24 | +0.0042 | 24 | +0.0210 | 22 | +0.0208 | 24 | +0.0168 |
| | 44 | +0.0123 | 48 | +0.0217 | 48 | +0.0209 | 48 | +0.0148 |
| | 72 | +0.0186 | 72 | +0.0219 | ... | ..... | 72 | +0.0139 |
| | 120 | +0.0217 | 120 | +0.0218 | ... | ..... | 120 | +0.0141 |
| | 192 | +0.0226 | 192 | +0.0219 | ... | ..... | 192 | +0.0148 |
| 2 | 3 | +0.0003 | 3 | +0.0020 | 3 | +0.0028 | 3 | +0.0023 |
| | 7 | +0.0016 | 7 | +0.0032 | 7 | +0.0033 | 7 | +0.0026 |
| | ... | ..... | 16 | +0.0041 | 16 | +0.0036 | 16 | +0.0016 |
| | 24 | +0.0021 | 24 | +0.0038 | 24 | +0.0037 | 24 | +0.0016 |
| | 44 | +0.0037 | 48 | +0.0041 | 48 | +0.0036 | 48 | +0.0004 |
| | 72 | +0.0035 | 72 | +0.0043 | ... | ..... | 72 | +0.0002 |
| | 120 | +0.0042 | 120 | +0.0043 | ... | ..... | 120 | +0.0012 |
| | 192 | +0.0045 | 192 | +0.0045 | ... | ..... | 192 | +0.0028 |
| 3 | 3 | +0.0006 | 3 | +0.0019 | 3 | +0.0022 | 3 | +0.0026 |
| | 7 | +0.0009 | 7 | +0.0025 | 7 | +0.0030 | 7 | +0.0032 |
| | ... | ..... | 16 | +0.0035 | 16 | +0.0036 | 16 | +0.0031 |
| | 24 | +0.0020 | 24 | +0.0034 | 22 | +0.0038 | 24 | +0.0035 |
| | 44 | +0.0031 | 48 | +0.0037 | 48 | +0.0040 | 48 | +0.0026 |
| | 72 | +0.0030 | 72 | +0.0040 | ... | ..... | 72 | +0.0025 |
| | 120 | +0.0037 | 120 | +0.0041 | ... | ..... | 120 | +0.0034 |
| | 192 | +0.0040 | 192 | +0.0044 | ... | ..... | 192 | +0.0050 |

**Table 7**
*(Continued)*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 3 | +0.0001 | 3 | +0.0005 | 3 | +0.0004 | 3 | −0.0003 |
| | 7 | +0.0004 | 7 | +0.0006 | 7 | +0.0005 | 7 | −0.0003 |
| | .. | ..... | 16 | +0.0008 | 16 | +0.0004 | 16 | −0.0004 |
| 4 | 24 | +0.0003 | 24 | +0.0006 | 22 | +0.0004 | 24 | −0.0004 |
| | 44 | +0.0008 | 48 | +0.0005 | 48 | +0.0002 | 48 | −0.0008 |
| | 72 | +0.0005 | 72 | +0.0007 | ... | ..... | 72 | −0.0009 |
| | 120 | +0.0009 | 120 | +0.0007 | ... | ..... | 120 | −0.0004 |
| | 192 | +0.0009 | 192 | +0.0007 | ... | ..... | 192 | +0.0008 |
| | 3 | −0.0004 | 3 | +0.0002 | 3 | +0.0003 | 3 | −0.0002 |
| | 7 | +0.0001 | 7 | +0.0003 | 7 | +0.0004 | 7 | −0.0001 |
| | ... | ..... | 16 | +0.0006 | 16 | +0.0004 | 16 | −0.0001 |
| 5 | 24 | −0.0002 | 24 | +0.0004 | 22 | +0.0005 | 24 | −0.0001 |
| | 44 | +0.0001 | 48 | +0.0004 | 48 | +0.0004 | 48 | −0.0005 |
| | 72 | −0.0001 | 72 | +0.0005 | ... | ..... | 72 | −0.0008 |
| | 120 | +0.0005 | 120 | +0.0006 | ... | ..... | 120 | −0.0003 |
| | 192 | +0.0004 | 192 | +0.0007 | ... | ..... | 192 | +0.0008 |
| | 3 | +0.0002 | 3 | 0.0000 | 3 | +0.0008 | 3 | +0.0001 |
| | 10 | −0.0001 | 7 | +0.0006 | 10 | +0.0011 | 7 | −0.0001 |
| | 18 | −0.0001 | 15 | +0.0008 | 18 | +0.0010 | 15 | −0.0013 |
| 6 | 25 | −0.0002 | 23 | +0.0013 | 25 | +0.0009 | 22 | −0.0006 |
| | 49 | +0.0005 | 47 | +0.0017 | 49 | +0.0009 | 46 | +0.0002 |
| | 73 | +0.0005 | 72 | +0.0019 | 72 | +0.0009 | 70 | −0.0001 |
| | 121 | +0.0009 | 120 | +0.0020 | 121 | +0.0008 | 118 | +0.0002 |
| | 192 | +0.0014 | 192 | +0.0019 | 192 | +0.0004 | 190 | −0.0005 |

shorter periods of heating at the lower temperatures and dropped off for longer periods at these temperatures. After reheating to the higher temperatures, serious losses in strength were observed in all alloys investigated. Alloys 2 and 4 in the heat treated

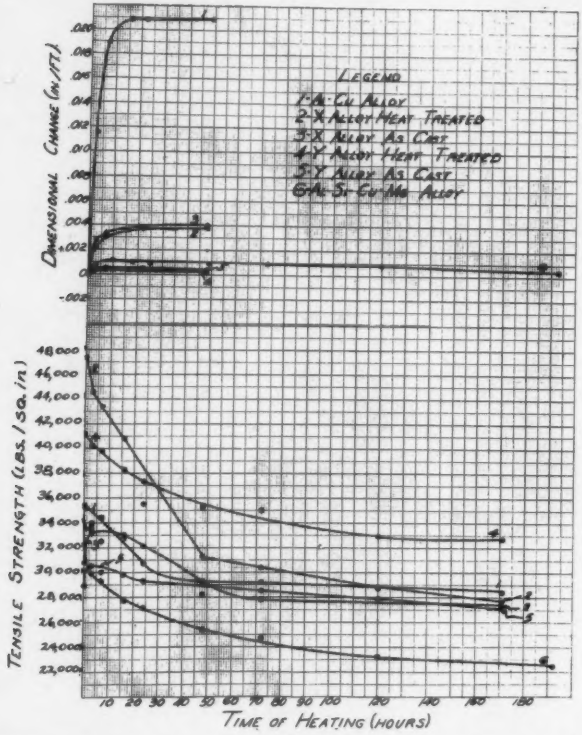


FIG. 7—CURVES SHOWING DIMENSIONAL CHANGES AND TENSILE STRENGTHS OF BARS AFTER HEATING TO 475 DEGREES FAHR. FOR VARIOUS TIME INTERVALS.

condition showed the best physical properties under all conditions of heating while alloy 6 had the lowest tensile strength and hardness especially after heating to the higher temperatures.

33. The results of tests on "as cast" alloys 3 and 5 indicate that at least some of the soluble constituents were retained in solid solution as the castings cooled from the molten state in green sand molds. The constituents were precipitated when the castings were reheated as was indicated by the increase in strength and hardness

of the test specimens after reheating to the lower temperatures. The physical properties of the alloys in the as cast condition were much lower than those of the same alloys in the heat treated condition after exposure to elevated temperatures indicating that heat treatment has a definite value even when the parts are to be exposed to temperatures in the annealing range in service.

34. *Y* alloy (4 and 5) showed great dimensional stability after heating, the total amount of permanent growth amounting to less than .001 inch per foot. Alloy 6 also showed very small changes in length as a result of reheating, the aging treatment evidently serving to stabilize the alloy. *X* alloy (2 and 3) showed a small amount of permanent growth after reheating which would be negligible under all but the most exacting conditions.

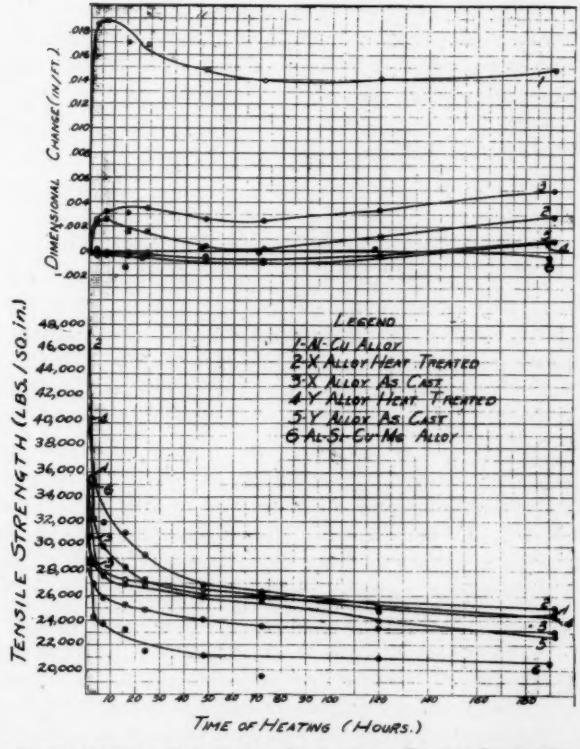


FIG. 8—CURVES SHOWING DIMENSIONAL CHANGES AND TENSILE STRENGTHS OF BARS AFTER HEATING TO 550 DEGREES FAHR. FOR VARIOUS TIME INTERVALS.

35. Alloy 1 showed the greatest amount of permanent growth after reheating in all cases. The amount of growth observed after reheating to 350 degrees Fahr. was greater than after reheating to higher temperatures. At 550 degrees Fahr., in fact, the maximum amount of growth was observed after 7 hours' heating, the specimens contracting in length as the time of heating was extended.

36. It is interesting to note that those alloys which had the highest casting shrinkage and which showed the greatest amount of dimensional change in heat treatment also showed the greatest amount of permanent growth when exposed to elevated temperatures.

37. As alloy 6 is likely to be substituted for alloy 1 for many purposes, a comparison of these two alloys is of particular interest.

38. Alloy 6, while it has excellent casting properties and great dimensional stability, has low tensile strength and hardness after exposure to elevated temperatures. These factors should be considered in designing castings which are to be used at elevated temperatures.

## COMPARES TWO ALLOYS

39. In casting these alloys from the same patterns, the castings would vary in length by the difference in shrinkage between the alloys, if the shrinkage were not retarded by cores, etc. Castings poured from alloy 6, would be approximately 0.020 inch per foot longer than similar castings poured from alloy 1, a very appreciable difference in length in large castings. During heat treatment the alloy 6 castings would undergo no appreciable change in length, while the alloy 1 castings would shrink approximately 0.005 inch per ft. making a total difference in length of 0.025 in. per ft. between castings poured from the two alloys. When the castings were exposed to elevated temperatures, the alloy 6 castings would show little change in length while the alloy 1 castings would grow as much as 0.022 inch per ft. When completely stabilized the alloy 6 castings would be from 0.005 inch per ft. to 0.010 inch per ft. longer than the alloy 1 castings.

40. After heat treatment, alloy 1 is not fully aged, that is, it is used ordinarily after solution treatment at 960 degrees Fahr. without aging or with a short aging treatment at a low temperature as in this investigation the castings were aged for 2 hours at 300 degrees Fahr. Further aging tends to increase strength and hardness and lower the ductility of the alloy. For example, re-

heating test specimens from this alloy to 350 degrees Fahr. for 48 hours increased the tensile strength from 36,000 pounds per square inch to 39,000 pounds per square inch, the hardness from 74 Brinell to 95 Brinell and decreased the elongation in 2 inches from 6.8 to 1.5 per cent.

41. Alloy 6, when it is to be exposed to elevated temperatures in service, is given a heat treatment which will stabilize the alloy so that no permanent growth will take place in service. This treatment consists of aging the castings at 440 degrees Fahr. for 8 hours after solution treatment at 980 degrees Fahr. This stabilizing treatment puts the alloy in a slightly over aged condition, as the tensile strength of the alloy decreased on exposure to temperatures as low as 350 degrees Fahr. while all other alloys investigated increased in strength after the shorter periods of exposure at this temperature. A further indication that this alloy was in a slightly over-aged condition may be found in the fact that after shorter periods of aging at lower temperatures tensile strengths of 40,000 pounds per square inch and higher may be obtained in test bars, though a greater amount of permanent growth might be expected if the castings were exposed to elevated temperatures when in this condition.

## NORMALIZING TREATMENT IS DELETERIOUS

42. The "normalizing" treatment applied to some types of castings, such as cylinder heads, appears to have a deleterious effect on the properties of the castings. As has been stated, this normalizing treatment consists of reheating the castings, after standard heat treatment, to 500 to 550 degrees Fahr. for 2 to 5 hours. The results of this investigation indicate that the strength of the castings is reduced from 20 to 35 per cent by the normalizing treatment, the amount of reduction varying with the different alloys. With all alloys except alloy 1, the normalizing treatment seems unnecessary since aging treatments such as those used in this investigation should serve to stabilize the castings and remove any tendency toward permanent growth. Operations, such as shrinking in inserts, could be performed during the aging treatment.

43. Alloy 1, of course, requires some stabilizing treatment before use at elevated temperatures, but a less drastic treatment than that generally used should yield more desirable physical characteristics. An aging treatment at 400 degrees Fahr. for 15

hours after solution treatment should serve to stabilize the alloy so no permanent growth in service would be expected, while the tensile strength of the alloy would not be adversely affected.

### CASTING PROPERTIES OF ALLOYS

44. While the results of the investigation indicate that alloys 2 and 4 have the best tensile properties after heating to elevated temperatures, these alloys are rather difficult to cast especially when the castings are intricate and must be free from leakage as in cylinder head castings. Alloy 1 has better casting properties but again the production of castings free from leaks is difficult. Alloy 6 has excellent casting properties and castings free from leaks may be produced much more readily. Although the strength of this alloy is lower than that of the other alloys investigated, after exposure to elevated temperatures, it has given satisfactory service in liquid cooled cylinder head castings for aircraft engines.

### ACKNOWLEDGMENT

45. The author wishes to gratefully acknowledge the aid of Capt. A. J. Lyon, Army Air Corps, and J. B. Johnson, Chief of the Materiel Branch, Wright Field, under whose supervision this investigation was conducted, and of the staff of the metallurgical laboratory at Wright Field.

## DISCUSSION

L. W. KEMPF[1] and H. L. HOPKINS[1], (*Presented in Written Form*): The effect of the elevated temperatures encountered in the normal operation of aircraft engines, on the properties of the materials utilized in their construction can hardly be too greatly emphasized. Therefore, Mr. Kennedy's paper is timely in again calling attention to some of these effects.

A large number of factors must be considered in making the choice of an alloy for a particular aircraft engine part, among which may be enumerated:

(1) Mechanical properties at the operating temperature.
(2) The stability of properties under operating conditions.
(3) Density or dimensional changes at the operating temperature.
(4) Casting or other fabricating characteristics.
(5) Corrosion resistance.
(6) Effect of section variation and section thickness on mechanical properties.
(7) The ability of the alloy to produce leak-tight castings.
(8) Thermal conductivity.
(9) Thermal expansivity.
(10) Cost.
(11) Specific gravity.

[1] Aluminum Research Laboratories, Aluminum Co. of America, Cleveland, Ohio.

These are not all of the factors which must be considered but are sufficient to illustrate the complexity of the problem. Mr. Kennedy has given consideration to two or three of these factors. His tensile tests at room temperature, following prolonged exposure at elevated temperatures, give some indication of the effect of elevated temperatures on the various alloys. However, a better comparison is obtained if the properties of the alloys at the temperatures involved after long exposure to those temperatures are considered. Properties of all the common casting alloys, including those investigated by Mr. Kennedy, have been determined in this manner. The method has been described[2]. These data are available on request.

It is generally understood that most heat-treatable alloys undergo density and thus dimensional changes during the heat treating process.

**Table 1**

MAXIMUM UNIT LINEAR DIMENSIONAL CHANGES OF COMMON ALUMINUM ALLOY SYSTEMS REHEATED TO LOW TEMPERATURE.

| System | Temperature of Reheating Following Solution Treatment in Degrees Fahr. | Maximum Unit Linear Dimensional Change |
|---|---|---|
| Al-Cu | 440 | 0.0016 |
| Al-Si | 440 | 0.0017 |
| Al-Mg | 370 | 0.0016 |
| Al-$Mg_2Si$ | 440 | 0.0001 |
| Al-Ni | 440 | 0.0000 |

These changes are quite well understood and their magnitude quite accurately determined for various conditions. With regard to most commercial aluminum alloys, the high temperature solution treatment and quenching usually brings about a slight increase in density of the annealed or "as cast" casting. No change in density has been observed to take place over long periods of time at room temperature. At elevated temperatures, a decrease in density may occur, the extent of which is dependent on the time and temperature of reheating. With sufficient time at temperatures generally within the range 400 to 650 degrees Fahr., a definite minimum density is gradually obtained which then remains constant regardless of the prolongation of time of heating within this temperature range. These changes are well illustrated by the curves (Fig. 1 of this discussion) for a binary aluminum-copper alloy containing about 10 per cent copper.

It is to be understood that the magnitude of these density changes varies from system to system. The maximum changes of the various alloy systems may be compared on the basis of the maximum unit dimensional change on reheating to relatively low temperature of alloys saturated with the second element near the eutectic temperature and cooled rapidly enough to preserve the alloy in the superheated condition to room

[2] Templin and Paul, *Mechanical Properties of Aluminum and Magnesium Alloys at Elevated Temperatures;* A.S.T.M.-A.S.M.E. Joint Symposium on Effect of Temperature on the Properties of Metals; June 23, 1931.

[2] Howell and Paul, *Properties of Aluminum and Two of Its Alloys at Elevated Temperatures;* Metals & Alloys, vol. 5, p. 176, 1934.

temperature. Table 1 gives a few of the changes for the common aluminum alloy systems.

It may be noted from the curves of Fig. 1, that maximum growth varies slightly with the temperature of reheating and also its attainment is not coincident with the attainment of the maximum mechanical properties, as illustrated in the foregoing curves for Brinell hardness. In point of time, maximum growth is obtained considerably after maximum hardness. It has been found that, in sand castings, the optimum combination of tensile strength and ductility is obtained with even shorter aging periods than are required for maximum hardness. Commercial practice

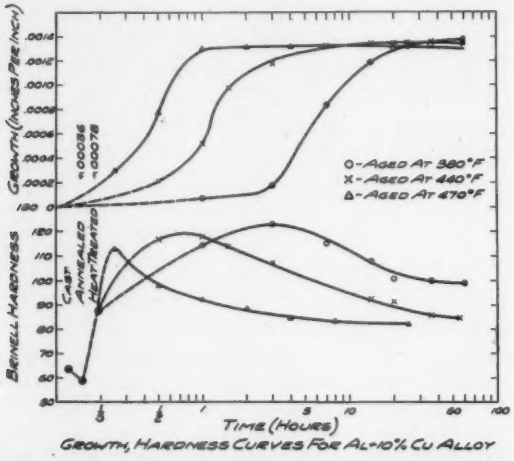


FIG. 1—GROWTH AND HARDNESS CHANGE DURING HEAT TREATMENT OF AN ALUMINUM + 10 PER CENT COPPER ALLOY. THE ANNEALING TREATMENT CONSISTED OF 2 HOURS AT 650 DEGREES FAHR. FOLLOWED BY SLOW COOLING TO ROOM TEMPERATURE. THE SOLUTION HEAT TREATMENT CONSISTED OF 16 HOURS AT 1000 DEGREES FAHR. FOLLOWED BY QUENCHING IN WATER.

requires various combinations of properties and a number of heat treatments have been designed for producing various compromises of these factors: hardness, tensile strength, ductility, and growth.

It is obvious that the problem of making a proper choice of alloy and heat treatment is an exceedingly complex one, and it is not surprising that in some instances it might appear as though an improper choice of material has been made. Usually, however, especially when there has been a satisfactory mutual understanding between the user of castings and the producer, the selection of alloy and heat treatment is the result of a careful consideration of all the factors involved. Mr. Kennedy has done the aircraft manufacturers a laudable service in calling to their attention some of the factors involved in the choice of alloys for castings for aircraft.

# Investigation of the Composition of Common Cast Iron for Boilers†

By G. Sirovich*, Rome, and G. Vanzetti**, Milan, Italy

**Abstract**

*The authors have investigated the possibility of using a cheap mixture for cast iron boilers. Their problem was complicated by the fact that in Italy, only low-carbon, high-phosphorus, low-silicon pig iron is available at moderate prices. They tested a number of different mixtures, keeping close control of the chemical composition. Test bars from the different irons were subjected to transverse, deflection, and impact tests. Since boilers are likely to have sudden temperature changes, the coefficient of thermal expansion of the various irons was determined, but was found to be practically the same in every case. Important facts about the influence of phosphorus in cast iron were brought out by the tests made. The authors found that the influence of phosphorus depends on the concentration of the other elements in the iron. From their work, they concluded that a low-carbon, high-silicon, high-phosphorus iron is not only cheap to make, but also is superior in physical properties to a low-phosphorus iron. The high silicon in such irons is obtained by the use of ferrosilicon additions, as this is more economical than buying a high-silicon pig iron.*

1. The use of common cast iron for the construction of boilers is constantly increasing. In the past, it has been used only in special cases of little importance, such as for concentrating boilers where the pressure was only a few lbs. per sq. in., for boilers for the chemical industry with the same pressure conditions, for boilers for domestic use, or for the production of a limited amount of steam at a pressure not over 15 to 30 lbs. per sq. in.

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† Exchange paper presented on behalf of the Italian Foundry Association.

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** Managing Director, Fonderia Milanese di Acciaio Vanzetti.

Note: This paper was presented at one of the Cast Iron sessions at the 1934 Convention of the A.F.A.

2. Today, most of the limitations against cast iron in the specifications of the different nations have been cancelled, so that the casting industry now has an important field for its product. However, in most countries, the maximum allowable pressure for cast iron boilers is still very low. In Italy, according to the specifications of December 1, 1927, it is necessary that a hydraulic test be made at one and one-half times the working pressure, and that the maximum pressure of this hydraulic test be not more than 21 lbs. per sq. in. The wall of a cast iron boiler is usually a very heavy section, and cast iron boilers without doubt will be easy to manufacture and will prove advantageous in operation, if well chosen for the particular use in question. The efficiency of cast iron boilers is approached only by steel boilers which often are preferred, although their construction is quite difficult.

3. The cost of the material of cast iron boilers is naturally a large item in the cost of the finished article, and using a cheap mix is of great advantage. Often it is the only way in which cast iron can compete with mild steel.

4. It is obvious that except for some very particular cases, it will be economically impossible to use a special cast iron, because we cannot use any of the many known methods for producing a specified structure in cast iron without increasing the cost of manufacture. It is, therefore, necessary to study the composition of the charge to determine what cast iron can be used.

## DISCUSSES COMPOSITION OF CHARGE

5. It is necessary to have a cast iron with a decisively gray fracture, of such composition that it will be impossible to have an accidental formation of white iron, even though present as a very small proportion of the structure as a whole. This is necessary because white iron is very brittle and also because a boiler casting should be easily machinable. There is, moreover, a possibility of breakage when the boiler is fired if both white and gray iron structures are present, because of the different coefficients of expansion.

6. In determining the composition of the mixtures for boiler castings, it is wise to refer to the diagram of Maurer and Holtzhausen[1*]. Their diagram for castings made in molds which are not preheated, shown in Fig. 1, is especially useful.

* Superior numbers indicate references at end of paper.

7. In this diagram we distinguish five distinct zones:

(I) White Cast Iron
(IIa) Transition or Mottled Cast Iron
(II) Pearlitic Gray Iron
(IIb) Transition of Pearltic and Ferritic Cast Iron
(III) Gray Ferritic Cast Iron

8. To be sure of obtaining an exclusively gray structure each time, even with a high cooling rate (although this is always kept within the limits which are practical for casting in green sand), it is necessary to keep in the third region and on the right side of the line *KJ*. For this diagram, the classification of cast iron is based only on the carbon and silicon contents although it is well known that manganese exerts too strong an influence on the structure of castings to be disregarded, even in the percentages found in ordinary cast iron. As the Maurer and Holtzhausen diagram shows cast iron with a manganese content from 1.03 to 1.12 per cent, then if the manganese concentration is that of ordinary practice, it is possible to get a really gray cast iron even with a composition in region IIb to the right of line *HG*. But it is evident that to get the desired cast iron, it is necessary to keep both carbon and silicon high.

## RAW MATERIALS AVAILABLE

9. This condition is very costly. First, only pig iron made with a high superheat in the blast furnace, which means a greater

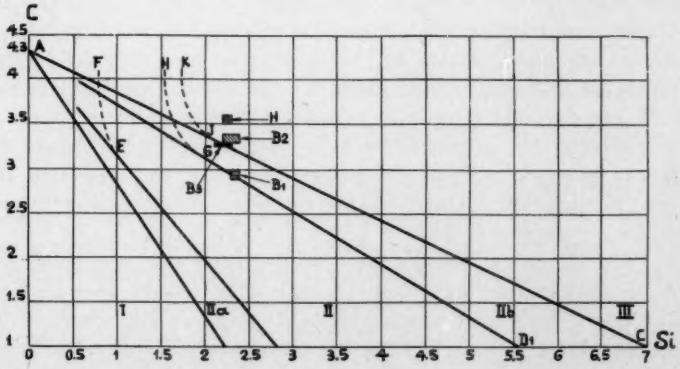


FIG. 1—MAURER AND HOLTZHAUSEN'S DIAGRAM FOR CAST IRON.

consumption of coke, contains a relatively high percentage of these elements. Second, such a mixture is closely limited and often excludes the possibility of the use of scrap, because it may have either steel or iron, and has already been remelted, and therefore contains less carbon and silicon than pig iron.

10. It is very difficult to fulfill this condition in the post-war period, especially since European furnaces are effecting the maximum economy of combustible material. The result of this is that the low priced material on the market has a low concentration of carbon and silicon. Pig iron with higher concentration of these elements commands a very high price, because of the superheat necessary to produce them.

### FERROSILICON IS LESS EXPENSIVE

11. This is particularly felt in Italy, where the complete lack of coke which is suitable for the production of pig iron, and the high price of imported coke, is a big item in the cost of cast iron production. With respect to silicon, in Italy it is less expensive to add ferrosilicon to the mixture than to get it in the raw material. When ferrosilicon is made electrically, the cost of a unit of silicon per ton of cast iron is appreciably less, when the silicon is added in the form of ferroalloy, than when obtained from the pig iron.

12. On the contrary, it has been impossible up to now to find a practical method of adding carbon to the amount used in the charge. It is, therefore, necessary to use a special pig iron, as stated above, or to use some pig like hematite to get a relatively high carbon content. One would normally use such kinds of pig iron to get a low phosphorus content, which, according to some authorities, should not be above 0.70 per cent for boilers. Some specifications, among them the Italian, have a maximum of 0.60 per cent phosphorus for steam generators or boilers used at a relatively high pressure (90 to 150 lbs. per sq. in.) although the best writers on the subject suggest between 0.60 and 1.00 per cent phosphorus.[2] Thus we have touched another important side of the economic question.

13. In Italy, and in most of the European countries, economic Nationalism has placed a high duty on pig iron imports. However, there is a special kind of imported pig iron on the market which is cheaper than the pig produced locally. It is the well known "Luxemburg 3" pig iron, so called because when it

was previously on the market it came from Luxemburg. Today, it is also produced in France, Germany and any centers where they have iron ore of lake origin, a brown hematite with high prosphorus content. They call that type "Minette."

14. The composition of this Luxemburg-3 pig iron is as follows: Carbon, 3.20 to 3.50 per cent; silicon, 1.90 to 2.30 per cent; manganese, 0.40 to 0.50 per cent; phosphorus, 1.75 to 2.00 per cent; sulphur, under 0.06 per cent. The possibility of using high phosphorus in iron for boilers has two advantages: First, the use of a mixture of more or less low priced material, such as the Luxemburg-3 pig iron, and second, the possibility of lowering the carbon content in the liquid melt without adding to the cost of obtaining a uniform casting.

15. It is well known that if the carbon content is decreased without adjusting the concentration of the other elements, it is necessary to raise the casting temperature to have the same fluidity. The reason for this is that the solidification point of iron rises approximately 91 degrees Cent. (164 degrees Fahr.) for every per cent carbon that is lost. By suitable phosphorus additions, it is possible to counteract the effect of lowered carbon and to get the desired fluidity without raising the casting temperature, because every per cent of phosphorus added will lower the solidification point of iron 53.7 degrees Cent. (96 degrees Fahr.).[3] Technical authorities differ as to the advisability of raising phosphorus in cast iron used for boilers, because it is generally admitted that, other things being equal, this element makes iron more brittle. From our experience, which has been proved by more than ten years industrial work, we are convinced that additions of phosphorus can be made without trouble if the carbon content is sufficiently decreased and if we avoid getting into the white iron zone by controlling silicon and manganese concentrations.

## TESTING THE IRONS

16. Our problem is molding and pouring a great number of identical castings. It is easy to control the variation in physical properties by changes in the composition of the material, and it has been established by a great number of tests that these properties are not influenced by incidental causes.

17. The shape of the cast bar was such that we could get good results without any machining, and consequently without disturbing the outside casting skin. Impact tests were made in

flexure, by a pendulum arm like the Charpy pendulum. We used an unnotched test bar, because, as is well known, the inevitable effect of the notch—especially when the material under test is one which does not allow any plastic deformation—makes the results inaccurate, and therefore without any real practical value. In addition, making even the slight cut for the notch in the outside casting skin may penetrate into another zone of entirely different nature. The outside skin plays a very important part in local resistance of the casting.

**Table 1**

CHEMICAL AND PHYSICAL PROPERTIES OF THREE CAST IRONS

| | Analysis | | | | | Properties* | | |
|---|---|---|---|---|---|---|---|---|
| Iron | Silicon | Total Carbon | Phosphorus | Manganese | Sulphur | Transverse (load-lbs.) | Deflection (1"1000) | Impact (Kg.) |
| H | 2.03 | 3.44 | 0.64 | 0.70 | 0.048 | 2720 | 205 | 1.30 |
| D | 2.13 | 3.48 | 0.83 | 0.71 | 0.077 | 2570 | 181 | 1.00 |
| B | 2.37 | 2.95 | 1.12 | 0.54 | 0.136 | 2996 | 178 | 1.24 |

* Transverse and deflection data obtained by slow flexure test.

18. *Impact Tests*—The impact test was made as follows: Distance between supports, 180 millimeters (7.1 inches), weight of the hammer, 2.640 kilograms (5.8 pounds), distance of drop 562 millimeters (22.1 inches). The results obtained are given in Table 1, which also contains the chemical composition of the different irons and the physical properties obtained in a slow flexure test. It should be kept in mind that these are not single results, but are the average of the results obtained in 30 working days in which two tests per day were made, and also that several thousand pieces of each type of cast iron were tested.

19. *Analysis*—The analysis of the irons was noted with the most rigorous exactness, as were the test results. For type *H* cast iron, all English pig iron was used; for type *D*, a French pig iron; and for type *B*, Italian pig iron. Other constituents were kept constant in each type by the additions of scrap, and, in some cases, ferrosilicon.

20. *Effect of Phosphorus on Impact*—It is immediately evident that it is not the phosphorus content proper which influences brittleness, because cast iron *B* has more phosphorus than the others, yet has a higher impact strength than iron *D*. Type *H*, which has the lowest phosphorus, has the highest impact strength. The work under consideration brought out another most import-

ant point, that even with high phosphorus content it is possible to obtain high transverse strength. This is true provided that the carbon is lowered sufficiently, that the silicon is raised and that the manganese is lowered as much as possible, to avoid the formation of white iron. In fact, iron *B* has the highest transverse strength, notwithstanding its high phosphorus.

## EXPERIMENTAL HEATS RUN

21. *Iron H*—Basing our conclusions on these results, which are confirmed by the practice of more than ten years, we tried to find how to lower the cost of the mixture for cast iron used in the manufacture of boilers. The mix normally used was made entirely of different varieties of English pig iron and supplied an iron of the following composition, called *H*: silicon, 2.20 to 2.30 per cent; total carbon, 3.50 to 3.60 per cent; phosphorus, 0.60 to 0.70 per cent; manganese, 0.70 to 0.80 per cent. This iron was entirely gray, and, as can be seen from Fig. 1, is found in region III of Maurer and Holtzhausen's diagram. Manganese was lower than in the iron studied by those authors. Phosphorus was held low, following the conservative lines proposed by several technical men.

22. The manufacture of this iron was very expensive, because it was necessary to use all English pig iron, as stated previously. The ordinary type of pig iron on the Italian market has low total carbon. For example, in a commercial pig iron with medium phosphorus, the carbon is usually between 3.2 and 3.5 per cent. Therefore, it was necessary to use either a specially manufactured pig iron, or hematite, which is supposed to have between 3.5 and 4.0 per cent carbon, but which really hardly ever has over 3.75 per cent. If hematite had been used, we would have had trouble pouring the castings because, in view of the normal drop in carbon during melting, the charge would have had to be practically all hematite. However, we wanted to use some sprues and gates to bring the phosphorus content of the hematite down to the ordinary amount for Italian castings, under 0.90 per cent.

23. *Irons $B_2$ and $B_3$*—To be able to use the cheaper Italian pig iron, it was advisable to control the carbon and phosphorus so that we could use a small proportion of purchased scrap in addition to sprues and gates. Using a charge containing Italian

pig iron, it was decided to make castings with the following compositions, which we will call $B_2$ and $B_3$ respectively:

| | Silicon per cent | Carbon per cent | Phosphorus per cent | Manganese per cent |
|---|---|---|---|---|
| $B_2$ | 2.20 to 2.40 | 3.30 to 3.40 | 0.60 to 0.70 | 0.50 to 0.60 |
| $B_3$ | 2.10 to 2.30 | 3.25 to 3.30 | 0.60 to 0.70 | 0.55 to 0.65 |

The composition of these irons on the Maurer and Holtzhausen diagram is marked on Fig. 1.

## ITALIAN PIG USED IN MIX

24. When thoroughly analyzed, the cost of this mix was far lower than the charge of all English pig. But it was impossible to avoid the use of a small proportion of hematite, and we must admit that this mixture was not very different from the ordinary charge for high test cast iron. Also, we had great difficulty in obtaining uniform heats, the same as was experienced with the type *H* iron. This difficulty was caused by the low carbon content, which made the iron less fluid, and by the high silicon and low manganese which were necessary to get a completely gray iron. Such variations of the composition caused porosity and abnormal shrinkage cavities.

25. *Iron* $B_1$—The reason we decided to investigate a third mixture was that the material previously produced was not strong enough. This mixture, which we will call $B_1$, made castings of the following composition: silicon, 2.30 to 2.40 per cent; carbon, 2.90 to 3.00 per cent; phosphorus, 1.00 to 1.10 per cent; manganese, 0.50 to 0.55 per cent. The position of this iron on the Maurer and Holtzhausen diagram is marked $B_1$ in Fig. 1.

26. We decided on this composition, believing that the higher concentrations of phosphorus would not cause brittleness in ordinary cast iron if the carbon content were lowered. When that is done, it is necessary to have high silicon and as low manganese as possible, to keep in the gray iron zone shown in the Maurer and Holtzhausen diagram. We did not think it wise to go below 0.50 to 0.55 per cent manganese because, due to the scrap used, the sulphur content tended to become quite high. Therefore, we had to have enough manganese to counteract the sulphur.

27. With a total carbon of from 2.90 to 3.00 per cent, we could use a higher proportion of scrap in the charge. Also, if necessary, we could use a cheaper type of common Italian pig iron. To get the high silicon content desired, we were obliged to

add ferrosilicon, but the cost of this element per ton of mix is relatively small in Italy.

28. Experimental production was continued on each type of cast iron for thirty working days, and the results obtained are shown in Table 2.

29. We did not attempt to find the impact strength in flexure, because the shape of the casting was such that we could not get a test bar which did not have to be machined. Besides, as our experience has shown, and as we have clearly demonstrated,

**Table 2**

Results Obtained from Four Experimental Boiler Irons

| | Analysis | | | | | Properties | |
|---|---|---|---|---|---|---|---|
| Iron | Silicon | Total Carbon | Phosphorus | Manganese | Sulphur | Transverse load-lbs. | Deflection, 0.001 in. |
| H | 2.22 | 3.51 | 0.62 | 0.70 | 0.051 | 2970 | 211 |
| $B_2$ | 2.21 | 3.33 | 0.70 | 0.62 | 0.085 | 2570 | 165 |
| $B_3$ | 2.15 | 3.32 | 0.70 | 0.62 | 0.083 | 2665 | 169 |
| $B_1$ | 2.40 | 2.97 | 1.06 | 0.54 | 0.137 | 3150 | 179 |

we need not fear increased brittleness caused by phosphorus provided it is properly counteracted by the lowered carbon. In any case, the dynamic stresses encountered in boiler operation can be considered incidental, because the variations of the stresses in the material are normally low. Consequently, the impact resistance is of little importance.

30. As to physical properties, it is indeed very important to note that, through raising the phosphorus content considerably, the resistance to slow flexure reaches a new value, much higher than that of low-phosphorus irons made from the English pig iron.

## Studies Heat Resistance

31. The property to which we gave the most attention was resistance to heat. This is especially important, because a great number of boilers are fired with oil. It is possible that the action of the flame may produce an abnormal internal stress, which would increase with the coefficient of expansion of the boiler.

32. Therefore it was decided to determine the coefficient of expansion and the expansion curve for each type of iron that we have described. Also, to ascertain the influence of different elements on this property, we cast similar boilers from different types of cast iron. The material used for these cast irons came

from the following sources: Type *S*—German pig iron, Type *V*—Belgian pig iron, Type *A*—French pig iron, Type *W*—Austrian and German pig iron.

33. *Determination of Expansion*—Expansion curves were made with a dilatometer with a mirror made by Le Chatelier-Broniewsky.[4] The test bar used was exactly 100 millimeters (3.9 inches), and was cut from the side of the boiler in such a way that the side and top of the test bar had the casting skin intact. These curves were made at a temperature of 400 degrees Cent. (752 degrees Fahr.) which was as high as we thought it worth while to go. In fact, this temperature is really higher than that to which the material will be subjected when it is in contact with the flame, because of the action of the water in the boiler.

34. The multiplication ratio for the ordinate at 400 degrees Cent. (752 degrees Fahr.) which is the only one measured to calculate the average expansion, was determined experimentally at intervals, and the factor is equal to 80. The ordinates of these curves show all the different expansions which have taken place in the bar, as compared to the expansion of the vitreous silicon support.

## EXPLANATION OF EXPANSION CURVES

35. Notice the values for the expansion curve of the different types of iron tested, as shown in the tables. Table 3 shows the chemical analysis of the irons from which the test bars were taken. Table 4 includes the room temperature at the beginning of the test. This temperature is necessary so that the average coefficient of expansion up to 400 degrees Cent. (752 degrees Fahr.) can be calculated from these curves. It is possible to calculate only three significant figures, because this is the accuracy of the values at 400 degrees Cent. However, the average coefficient so calculated is the same for each type of iron as if it had been determined experimentally between 0 and 400 degrees Cent.

36. The curves for the expansion of different types of irons are given in Fig. 2. Even a superficial glance shows the perfect symmetry of all the curves. It is clear, from these curves, that differences in composition have very little effect on expansion, provided the iron is perfectly gray. This fact is even more evident when we calculate the average coefficient of expansion. Table 4 gives these coefficients for the test bars taken from the castings on which we made physical tests and for the test bars obtained

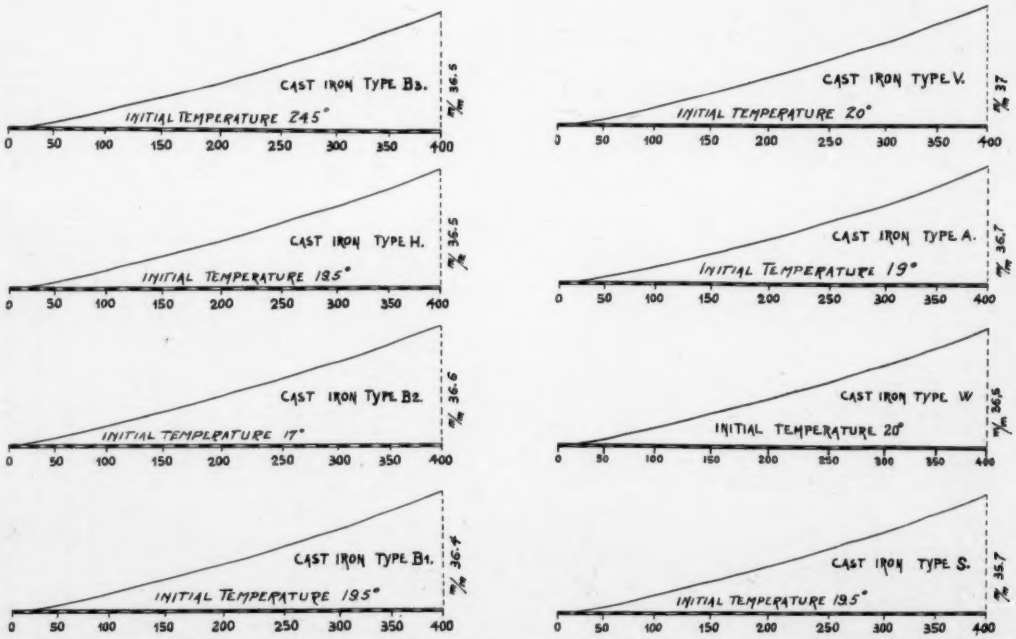


FIG. 2—EXPANSION CURVES FOR VARIOUS TYPES OF IRONS STUDIED. ANALYSES OF THESE IRONS WILL BE FOUND IN TABLE 3.

**Table 3**

CHEMICAL ANALYSIS OF IRONS USED TO DETERMINE COEFFICIENT OF EXPANSION

| Iron | Silicon, Per cent | Combined Carbon, Per cent | Graphitic Carbon, Per cent | Total Carbon, Per cent | Manganese, Per cent | Phosphorus, Per cent | Sulphur, Per cent |
|---|---|---|---|---|---|---|---|
| $B_3$ | 2.09 | 0.67 | 2.57 | 3.24 | 0.56 | 0.61 | 0.146 |
| H | 2.28 | 0.65 | 2.95 | 3.60 | 0.78 | 0.71 | 0.086 |
| $B_2$ | 2.36 | 0.59 | 2.80 | 3.39 | 0.59 | 0.63 | 0.110 |
| $B_1$ | 2.41 | 0.66 | 2.33 | 2.99 | 0.54 | 1.02 | 0.135 |
| V | 2.20 | 0.62 | 2.77 | 3.39 | 0.79 | 0.57 | 0.092 |
| A | 2.05 | 0.56 | 2.78 | 3.34 | 0.66 | 0.54 | 0.068 |
| W | 2.28 | 0.50 | 2.75 | 3.25 | 0.57 | 0.87 | 0.071 |
| S | 2.21 | 0.35 | 3.10 | 3.45 | 0.59 | 0.59 | 0.074 |

**Table 4**

COEFFICIENT OF EXPANSION OF IRONS GIVEN IN TABLE 3

| Iron | Room Temperature °C | Room Temperature °F | Ordinate at 400° C (752° F) | Coefficient of Expansion — Relative | Coefficient of Expansion — Actual |
|---|---|---|---|---|---|
| $B_3$ | 24.5 | 76 | 36.5 | 0.0000121 | 0.00001269 |
| H | 19.5 | 67 | 36.5 | 0.0000120 | 0.00001259 |
| $B_2$ | 17.0 | 62 | 36.6 | 0.0000119 | 0.00001249 |
| $B_1$ | 19.5 | 67 | 36.4 | 0.0000119 | 0.00001249 |
| V | 20.0 | 68 | 37.0 | 0.0000122 | 0.00001279 |
| A | 19.0 | 66 | 36.7 | 0.0000120 | 0.00001259 |
| W | 20.0 | 68 | 36.5 | 0.0000120 | 0.00001259 |
| S | 19.5 | 67 | 35.7 | 0.0000117 | 0.00001229 |

from the heats made with various foreign pig irons. These tables are arranged in the order of decreasing expansion.

37. For the calculation of the coefficient of expansion, we have assumed that the value for the coefficient of expansion of vitreous silicon, which is given by Cohn[5] as 0.00000059 between 0 and 400 degrees Cent., is exact. To compare the composition of the test bars used in these tests, we have checked the composition with the Maurer and Holtzhausen diagram, shown in Fig. 3. Iron $B_3$ has the greatest expansion in the first group of cast irons and type $B_1$ has the least. $B_3$ has a fairly low phosphorus content, while $B_1$ has a higher percentage. Therefore, lowering phosphorus will not help reduce expansion. Since iron $H$ shows a coefficient of expansion just intermediate between $B_3$ and $B_1$, there is no need to raise the carbon.

38. It would seem from the data on these four irons as if

higher silicon would lower the coefficient of expansion, because irons $B_2$ and $B_3$ have practically the same percentages of other elements. However, this idea is not confirmed by the other tests on irons *V*, *A*, *W*. and *S*. Iron *V*, with the largest coefficient of expansion, and iron *S*, with the least, have practically the same silicon content.

39. Not even the position of the various types of iron on the Maurer and Holtzhausen diagram indicates the influence of silicon and carbon on the coefficient expansion. The same conclusion can be reached about other elements, whether considered separately or in combination with each other.

## RESULT OF EXPANSION TESTS

40. We may conclude that as long as an iron is decisively gray, variations of the normal concentration of the common elements (silicon, carbon, phosphorus, manganese and sulphur) affect the coefficient of expansion very little. In fact, all the irons (except *S*, of which we will talk later) show a coefficient of expansion between 0.00001279 for *V* and 0.00001249 for $B_1$. The range of the coefficient of expansion is, therefore, within 0.0000003.

41. This small difference cannot have any influence on the actual service of boilers at high temperatures. This conclusion is confirmed by very simple reasoning, as follows: Vitreous silicon, as we have stated previously, shows a coefficient of expansion of 0.00000059. When this is heated to a yellow color at 950 to 1000 degrees Cent. (1742 to 1832 degrees Fahr.) or even higher, and

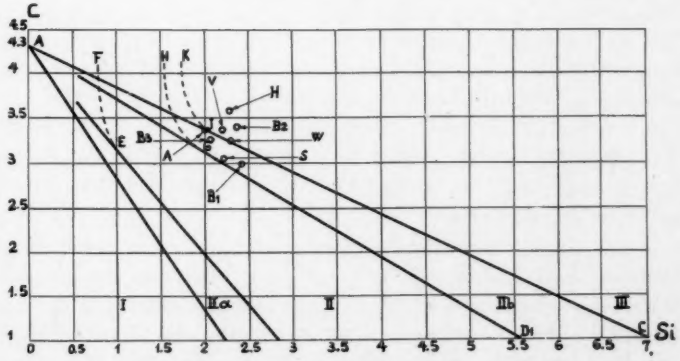


FIG. 3—MAURER AND HOLTZHAUSEN'S DIAGRAM SHOWING POSITIONS OF THE VARIOUS IRONS STUDIED.

is quenched in water, it is cooled very quickly and irregularly, because of the inevitable formation of steam. Yet this material remains intact although far more brittle than cast iron, because its low coefficient of expansion does not permit the thermal tension to cause breakage.

42. This experiment can be made many times, always with the same results. However, the coefficient of expansion of vitreous silicon is almost double the variation that can be present in the coefficient of common gray cast iron (0.0000003). From this example, we may conclude that the effect of the fire blow would be practically the same on all the irons in question.

43. Iron *S* still stands out from the other irons tested for its low coefficient of expansion, which is .00001229, although its composition is only slightly different from iron *V*, which has the highest coefficient, .00001279. Iron *S* has an extraordinarily low combined carbon content. It would seem that to increase the heat resistance of cast iron, we should obtain an iron with low combined carbon.

## EXPLAINS MICROSTRUCTURES

44. In addition to the factors which are recognized as influencing combined carbon, there are others which are not well established and which are of something like hereditary origin. These were once denied, but today most technical men admit their existence. The combined carbon is also doubtless influenced by the gaseous elements in the iron, such as oxygen, hydrogen, nitrogen, etc.

45. The first thing to do before investigating these factors is to confirm the fact that iron with exceptionally low combined carbon will actually have the lowest coefficient of expansion. We did not make a complete study on this point, nor try to find the iron with the lowest coefficient of expansion. Our aim was to find a gray cast iron with physical properties suitable for the manufacture of boilers.

46. To complete our work, we studied the structures of sections of the expansion bars. Thirty-two microphotographs were taken at a magnification of 200x. Four microphotographs were taken of each section; two etched in an alcoholic nitric acid, and two unetched. To see if we had any cementite in the cast iron, we also etched two with alkaline sodium picrate, but obtained

negative results. The microphotographs are shown in Figs. 4, 5, 6 and 7.

47. The unetched samples show uniformly distributed groups of thin lamellar graphite flakes, produced by the separation of graphite from nodules, or from large lamellae. This structure is clearer in irons $B_2$ and $S$ (microphotographs 9 and 29) than in the others.

48. Two microphotographs, both unetched and etched in alcoholic nitric acid solution, were made of each iron. One shows the graphite flakes, and the other shows the matrix.

49. In the unetched microphotographs, the graphite shows up black. We also see small diffused slag inclusions, although these are not always clearly visible. We can distinguish the characteristic cellular structure of steadite, or ternary iron-carbon-phosphorus eutectic. Steadite, which is very hard, stands out on the polished sample, and often will appear when the surface is merely cleaned. We cannot draw conclusions from our study of the etched microphotographs without considering the phenomena of solidification of such complex alloys as gray cast iron.

## Discusses Phenomena of Solidification

50. Sulphur reacts with manganese and is displaced by the products of that reaction, as can be seen in all the irons we have studied. The other elements, *i.e.* carbon, silicon, phosphorus and manganese, give rise in solidification to mixed crystals whose composition is determined by the original composition of the liquid cast iron. These crystals change gradually as the temperature decreases. The first crystals that separate are the purest. The concentration of the different elements correspond to, or are in direct proportion to, the original concentration in the liquid.

51. Therefore, when the carbon is higher in the liquid, there will be more carbon in the resulting crystals, as in type $H$. The concentration of phosphorus in crystals originating from phosphorus-rich liquids will be greater than otherwise, and this principle holds true for the other elements. In the first phase, solid solutions will always contain all four elements because all four combine directly with iron. As the deposition of the solid of each type of mixture continues, the mixed crystals become richer in the other elements besides iron, because the original liquid becomes more concentrated in these elements.

52. If solidification occurred at complete equilibrium, the

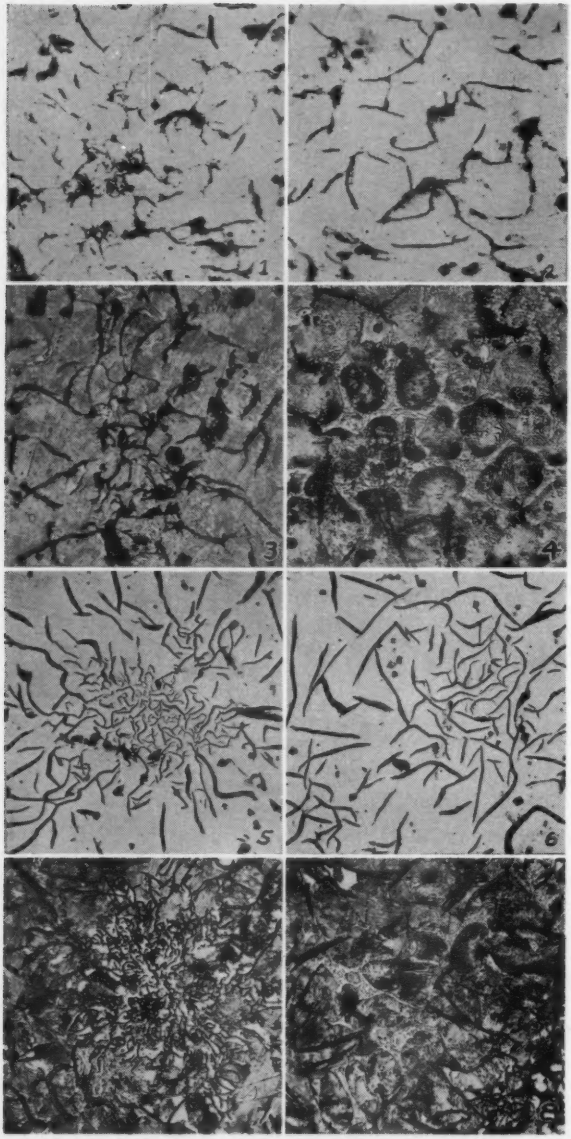


FIG. 4—MICROPHOTOGRAPHS OF SECTIONS OF IRONS $B_3$ AND $H$ AT 200X. 1 AND 2, $B_3$ IRON UNETCHED; 3 AND 4, SAME IRON ETCHED; 5 AND 6, IRON $H$, UNETCHED; 7 AND 8, SAME IRON ETCHED.

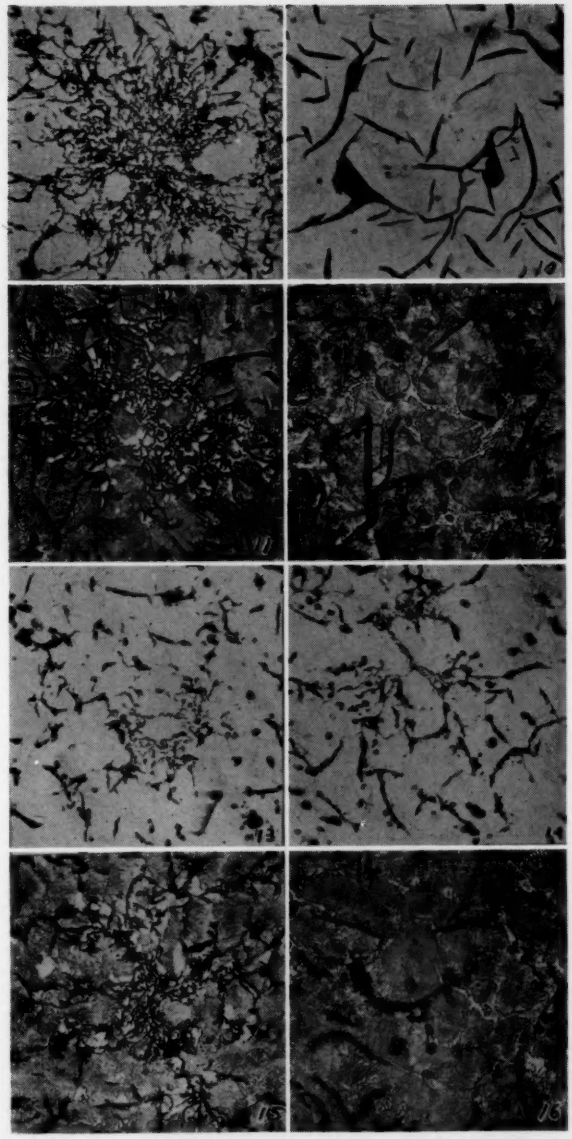

FIG. 5—MICROPHOTOGRAPHS OF SECTIONS OF IRONS $B_2$ AND $B_1$ AT 200X. 9 AND 10, IRON $B_2$ UNETCHED; 11 AND 12, SAME IRON ETCHED; 13 AND 14, IRON $B_1$ UNETCHED; 15 AND 16, SAME IRON ETCHED.

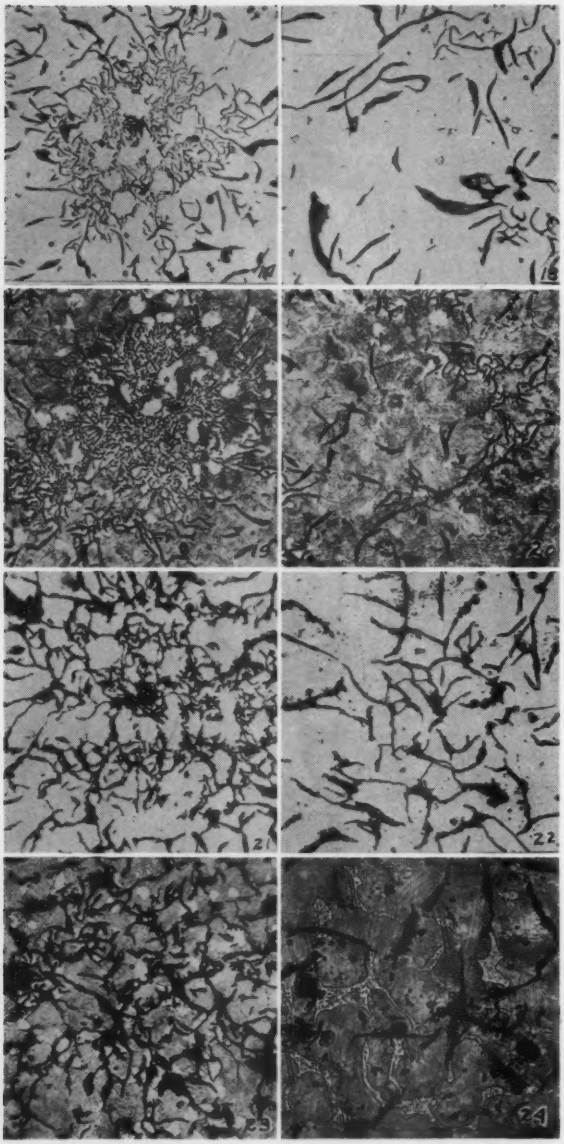

FIG. 6—MICROPHOTOGRAPHS OF SECTIONS OF IRONS *V* AND *A* AT 200X. 17 AND 18, IRON *V* UNETCHED; 19 AND 20, SAME IRON ETCHED; 21 AND 22, IRON *A* UNETCHED; 23 AND 24, SAME IRON ETCHED.

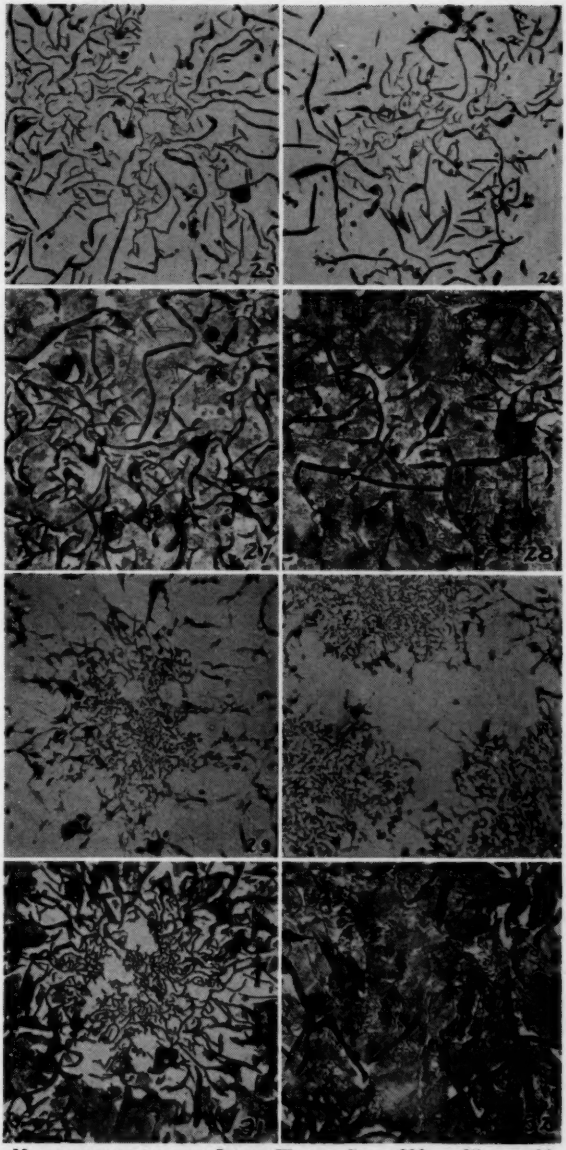

FIG. 7—MICROPHOTOGRAPHS OF IRONS *W* AND *S* AT 200X. 25 AND 26, IRON *W* UNETCHED; 27 AND 28; SAME IRON ETCHED; 29 AND 30, IRON *S* UNETCHED; 31 AND 32, SAME IRON ETCHED.

separation of one type of crystal would continue until the liquid phase became saturated with another element, and began to deposit this second element at the same time. This secondary separation would be carbon, because it forms a solid solution with iron, which is saturated when 1.7 per cent carbon is present. Manganese is completely miscible with iron in the solid state. Silicon is soluble up to approximately 25 per cent, and phosphorus up to approximately 3 per cent. In all probability (even remembering that this ratio may vary when it refers to complex systems instead of binary alloys), it would never be possible to reach the saturation point of any of the elements we have mentioned.

## EXPLAINS STEADITE FORMATION

53. When the cooling rate is such that the system is not at equilibrium, there is a greater concentration of other elements present in the liquid. Therefore, it is possible to have a simultaneous deposition of other phases. Steadite is formed in cast iron at much lower phosphorus content than we have given as the saturation point in the solid state. Silicon and manganese, even allowing for the variation in solubility which occurs in complex systems, will never be the cause of the separation of new phases, due to their relatively low concentration.

54. But what quantity of steadite will actually separate in the different types of cast iron used in these tests? Evidently, if the cooling rates are equal (they are practically the same for all cases considered), the amount of phosphorus in the liquid when steadite begins to be deposited will depend not only on the original phosphorus concentration in the liquid, but also on the amount subtracted from the liquid phase during the primary and secondary crystallizations. There may be cases where, even with the same rate of cooling, a liquid originally richer in phosphorus will show less steadite on solidification than other irons with relatively low phosphorus.

55. This is true especially when a liquid phase containing low phosphorus has high concentrations of elements which lower the solubility of phosphorus in iron. Carbon is the most important of these. In fact, the studies of Stead,[6] Fettweiss[7] and MacKenzie[8] show that the higher the carbon content, the less is the solubility of phosphorus in iron. In our work we found that the quantity of steadite present in the different irons is not in proportion to the total phosphorus concentration, but amount

present in each case is correct because the concentration of other elements is different, and this influences the solubility of phosphorus.

56. Since steadite is formed by the tertiary separation, it is obvious that it will be present in greater quantities in those parts of the metal which solidify last. Observing the microphotographs, we see that it always accumulates in the matrix, and that the zones occupied by the thin graphite flakes formed in the post-eutectic separation are usually absolutely free from steadite. Consequently, by comparing the zones in which the matrix is dense (shown in microphotographs 4, 8, 12, 16, 20, 24, 28 and 32), it is possible to judge which type of cast iron has the greatest precipitation of steadite.

57. Irons $B_3$ and $A$ (microphotographs 4 and 24) have the greatest quantity of steadite, in spite of the fact that both have low phosphorus and that iron $A$ has the lowest phosphorus of any of the irons studied. These two irons also have the lowest silicon concentration. This is in accord with what we have said, because as Morschel[9] stated, silicon limits the solubility of carbon in the solid state. The crystals of primary separation of these low-silicon alloys are richer in carbon, and therefore poorer in phosphorus. Phosphorus therefore remains in the liquid, and comes down in the tertiary separation as steadite.

## Conclusion

58. It seems that the type of cast iron we want is one with low carbon and high silicon (microphotograph 16). Although it contains almost twice as much phosphorus as the two irons previously discussed, it has less steadite than either of them, and less than most of the other irons considered. (It is understood that the total phosphorus of each iron is that given in the chemical analysis.) When there is only a small amount of steadite, it is mostly in a state of solid solution in ferrite, in a much less dendritic form than usual.

59. These observations confirm a fact that has already been noticed in considering the other physical properties, that a very high phosphorus iron may have improved physical properties if the concentration of the other elements is adjusted correctly.

60. The conclusions of this study on economical mixes for common cast iron for boilers can be stated as follows: It is shown that the goal can be attained by using iron with approximately 1

per cent phosphorus, and the lowest carbon that will give good fluidity. In any case, the carbon should be under 3.10 per cent. Silicon must be raised and manganese decreased so that the composition will fall in the zone of gray ferritic cast iron in the diagram of Maurer and Holtzhausen, and will assure a decidedly gray cast iron.

61. The limitations on phosphorus content which appear in some specifications are not justified, unless they are given in relation to the other elements. By increasing phosphorus to the maximum given by the best authorities, and by adjusting the concentrations of carbon, silicon and manganese, it is possible to obtain not only a marked drop in cost, but also a great improvement in physical properties.

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## DISCUSSION

HARRY RAYNER[1]: You state in the paper that the only pig irons you can obtain are those of low carbon. Could you not educate the blast furnace people from whom you get the pig iron to give you something similar to the pig iron mentioned by Dr. Piwowarsky so that you could obtain a higher carbon?

DR. VANZETTI: I did not mean that we could obtain only that type. What I meant was that it was cheaper. This is a special condition in our country, because the ferrosilicon is rather cheap. We import a lot of our pig iron and the cheapest is that which we get from Luxembourg. Therefore, it is a question of price.

HARRY RAYNER: The price of your product would be raised if you used the higher carbon pig, and therefore you adapt yourself to that which you have?

DR. VANZETTI: Yes, we have to use a rather low carbon pig iron because our phosphorus is rather high.

M. ONDREYCO[2]: I notice that you give some very interesting figures on the influence of phosphorus on expansion. Have you noticed any difference in the internal shrinkage between the high phosphorus and the low phosphorus compositions?

DR. VANZETTI: There is some difference, but not much. The castings we used are generally very thin, and it is not possible to observe much shrinkage.

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[1] Chrysler Corp., Detroit.

[2] Westinghouse Air Brake Co., Wilmerding, Pa.

# A Note on the Metallography of Ferrite in Malleable Cast Iron

By H. A. Schwartz* and C. H. Junge,* Cleveland.

**Abstract**

*Previous investigations by one of the authors led to the investigation of the possible heterogeneities of ferrite in malleable cast iron. It was found that an etching solution of hot concentrated alkaline sodium picrate produced a pattern in completely graphitized malleable iron which differed from that produced by an acid etch only in sharpness but that it differentiates between those areas that originally were cementite and those which were austenite. Silicon probably is responsible for that differentiation. Temper carbon nodules form preferentially on the austenite-cementite interfaces. By use of the etch pattern, it is possible to show that the ferrite and temper carbon structure is related to the original hard iron pattern. Further, it was found that even with long-time heat treatments, silicon or other elements that contribute to the etch pattern, diffuse so slowly in alpha and gamma iron that no equalization of concentration is produced.*

1. Some years ago, one of the authors[1]* pointed out that a dendritic pattern is obtained by etching malleable iron with a gently boiling alkaline sodium picrate solution sufficiently concentrated† so that heat tinting colors (Newton's interference colors) are produced when the sample is removed from the etching bath.

2. This observation led us to contemplate the possible inhomogeneities of the ferrite of malleable cast iron. From time to time, various observations by this and other methods have been made which it may be well to place on record at this time. Figs. 1 and 2 are micrographs at 30 diameters of hard iron etched with nital. The iron is the same but the rate of solidification was varied purposely. In Fig. 1, the metal froze in an exceedingly coarse

* National Malleable & Steel Castings Co.

1* The superior numbers refer to the bibliography at the end of the paper.

Note: This paper was presented at a meeting on Malleable Cast Iron at the 1934 Convention of the A.F.A.

† The solution must be sufficiently concentrated to bring its boiling point high enough to produce the colors; such solutions will partially crystallize on cooling to room temperature.

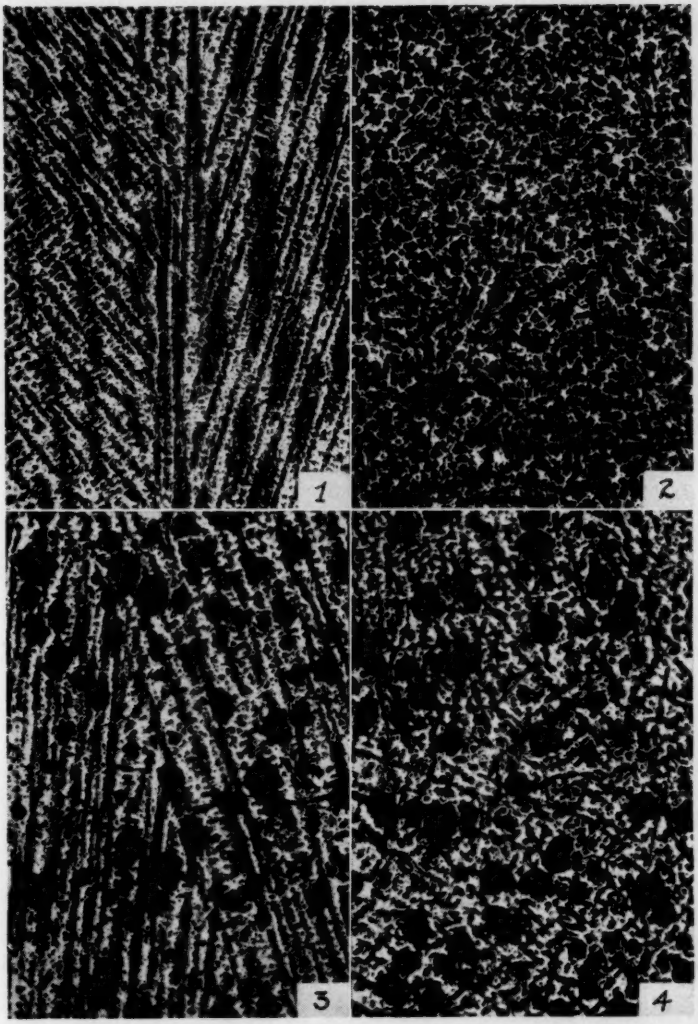


FIG. 1—HARD IRON IN WHICH THE SOLIDIFICATION RATE WAS CONTROLLED TO GIVE A COARSE DENDRITIC STRUCTURE. ETCHED IN NITAL, 30X. FIG. 2—HARD IRON IN WHICH THE SOLIDIFICATION RATE WAS CONTROLLED TO GIVE A GRANULAR STRUCTURE. ETCHED IN NITAL, 30X. FIG. 3—IRON IN FIG. 1 ANNEALED AND ETCHED WITH HOT ALKALINE SODIUM PICRATE SOLUTION, 30X. FIG. 4—IRON IN FIG. 2 ANNEALED AND ETCHED WITH HOT ALKALINE SODIUM PICRATE SOLUTION, 30X.

dendritic pattern; in Fig. 2, in a granular pattern. The metal was annealed and examined at 30 diameters after picrate etching with the results shown in Figs. 3 and 4. The relation between the pattern developed by the heat-tinting etch and the original hard iron pattern is at once apparent. The fields of view are not the same but it is clear that dendritic white iron produces a dendritic etch pattern and a granular white iron produces a granular etch.

3. One suspects that the areas which photograph white in Figs. 3 and 4 represent the location where cementite existed in the hard iron, at least the pattern is similar. One notes also in Fig. 3 that although the temper carbon dots alone would hardly suggest any regularity of pattern, yet they seem to be arranged with their centers rather close to the edges of the white areas of the figure.

## Temper Carbon Origination

4. Fig. 5 is a white iron (actually identical with Fig. 1) which has been heated just long enough (one hour) at 1472 degrees Fahr. (800 degrees Cent.) to produce a multitude of small temper carbon dots. These dots again show no visible symmetry by themselves but are seen to have originated at austenite-cementite interfaces. Those interfaces reappear in the picrate-etched malleable as boundaries between light and dark areas.

5. A portion of the same white iron then was annealed in such a manner that minute fragments of eutectic cementite were left but no pearlite and the specimen examined after picrate etching. Fig. 6, which is at 100 diameters, shows the result. The light areas contain the remaining tiny grains of cementite near their own axes and, hence, the light areas are where the cementite was in the hard iron rather than where the austenite was located.

6. It has not been shown whether the two correspond exactly in area but Fig. 3 suggests that the light etching areas occupy about the same fraction of the field of view as do the cementite areas of Fig. 1.

7. Lauenstein pointed out[2] that a network of combined carbon could be produced in malleable cast iron by reheating it but little above the $A_1$ point. In this case, carbon recombines at the grain boundaries only. Fig. 7, also at 100 diameters, is from a specimen of the same malleable cast iron which was so heat treated and then polished and etched in alcoholic nitric acid and then in alkaline picrate. Comparison with Fig. 6 shows first a complete

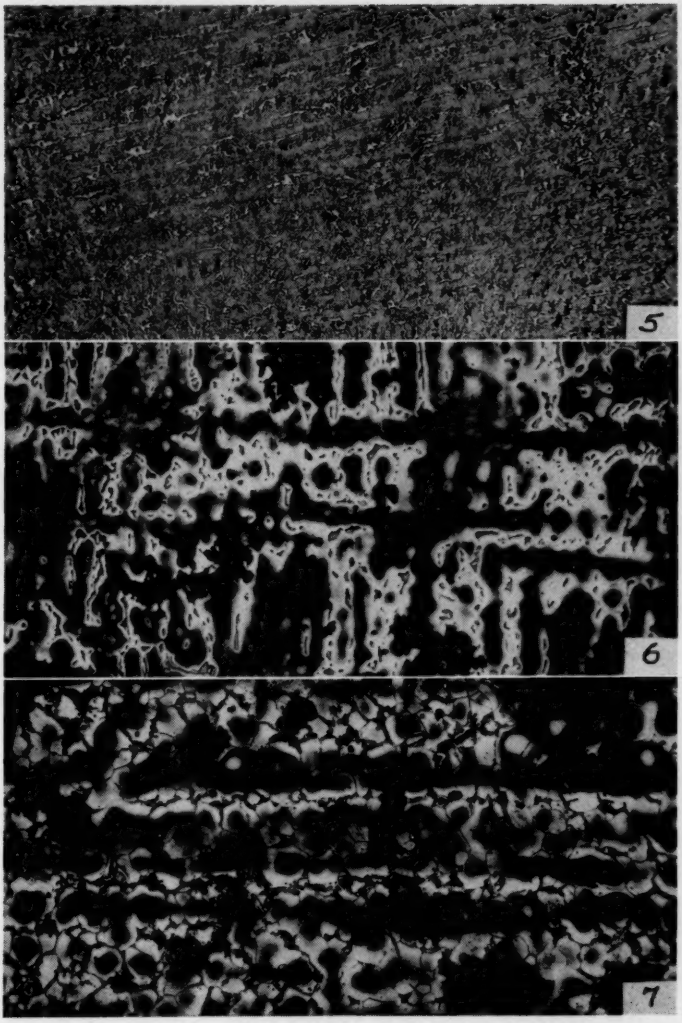


FIG. 5—A WHITE HEATED JUST LONG ENOUGH TO PRODUCE A MULTITUDE OF TEMPER CARBON DOTS. FIG. 6—SAME IRON AS IN FIG. 5 ANNEALED TO PRODUCE MINUTE FRAGMENTS OF EUTECTIC CEMENTITE BUT NO PEARLITE. SPECIMEN ETCHED WITH HOT ALKALINE SODIUM PICRATE SOLUTION, 100X. FIG. 7—MALLEABLE IRON REHEATED SLIGHTLY ABOVE THE $A_1$ POINT SHOWING CARBON RECOMBINED AT THE GRAIN BOUNDARIES. ETCHED WITH ALCOHOLIC NITRIC ACID AND THEN HOT ALKALINE SODIUM PICRATE SOLUTION, 100X.

net of well developed grain boundaries none of which were visible in Fig. 6, and second, that those boundaries, or better the regions where carbon has recombined, are much wider in the light colored areas than in the dark colored areas. It also is evident curiously that almost every light colored area has a line, the boundary of a series of grains, running down approximately its center line. Where there are differences of tint in the originally austenitic areas of the specimen, the grain boundaries rather generally run through the lighter colored regions, though exceptions can be found.

### FERRITE NOT CHEMICALLY HOMOGENEOUS

8. Our observations indicate that the ferrite of malleable cast iron is not chemically homogeneous either when comparing one grain with another or when considering an individual grain. The differences, as between different grains, are related to the original white iron structure. The ferrite, in areas which were originally cementite, is consistently different from that in areas which were originally austenitic. We have no evidence as to whether the heterogeneity of ferrite in those latter areas has a counterpart in austenite or not.

9. It is possible to graphitize high carbon alloys containing very little silicon. The picrate etch applied to an alloy containing about 0.03 per cent silicon and not over 0.05 per cent of all other elements except iron carbon and silicon develops no detectable pattern. Therefore, one is prone to consider the pattern brought out as caused by a segregation of silicon on a microscopic scale. Since high silicon steels are attacked rather strongly by the reagent, there is a suggestion that the areas etching lightly in the micrographs of this paper are low in silicon with the correlary that the originally cementitic areas are now lower in that element than the originally austenitic areas.

### SILICON AFFECTS ETCHING

10. The greater recombination of carbon in the grain boundaries passing through the light etching areas is reasonably in accord with the concept that at a given temperature these areas are further above their $A_1$ points than the darker areas, for the critical point rises with increasing silicon. On the other hand, it has been shown that alkaline picrate used in the usual manner does not darken cementite in silicon containing white cast iron as readily

as in the absence of silicon, which suggests that silicon must be soluble in cementite to affect its etching characteristics.

11. One of the authors, with Mrs. Hird[3], found that, especially with slow freezing, the electrolytically isolated carbides were accompanied by most of the silicon of the metal. No clear proof exists as to whether this silicon was dissolved in the carbide or not, except that the carbides had the X-ray spectrum of cementite. If the silicon were present in any undissolved form, we merely know that it did not manifest itself in that particular manner. Recent investigations of Mrs. Hird's samples show that their silicon content is volatile in Cl as $SiCl_4$ as is the silicon content of steels and cast irons and hence is not $SiO_2$. This does not mean that it is not a silicide residue mechanically mixed with carbides.

## CONCLUSION

12. We believe that the micrographs presented warrant the following conclusions:

(1) Etching with hot concentrated alkaline picrate develops in completely graphitized malleable a pattern differing in sharpness only from that obtained on acid etching the hard iron before anneal.

(2) The etching differentiates between the areas which were originally cementite and those which were austenite by attacking the latter much more readily than the former.

(3) The etching probably distinguishes between these areas on the basis of their silicon content although either Mn or P may also be involved.

(4) All ferrite grain boundaries seem to have a lower $A_1$ point than the centers of grains but those in what were cementite areas show this in greater degree than those in originally austenitic areas.

(5) Ferrite grain boundaries seem to favor the lighter etching zones and especially do they tend to form along the axes of the dendritic cementite.

(6) Temper carbon nodules form preferentially on cementite-austenite interfaces.

(7) Although both the ferrite and temper carbon structure is thus related to the original hard iron pattern, it is practically impossible to trace the relationship without the etch pattern as a guide.

(8) Silicon (or any other element contributing to the etch

pattern) diffuses so slowly in alpha or gamma iron that the long time heat treatments of malleable annealing produce no equalization of concentration.

(9) The ferrite grains of malleable may be enormously smaller than the dendritic crystallites which represent the original freezing pattern.

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# A Comparison of Some Wet Methods Used for the Fineness Test of Sands and Clays

By R. C. Hills*, Ithaca, N. Y.

**Abstract**

*In this paper, the author gives the results of an investigation of the better known wet methods for determining the fine-sized particles of clays, molding sands, soils, and other fine-grained natural or artificial substances. He gives special attention to molding sands, stating that their grain size is their most important single property. All the other properties of molding sands, such as strength, permeability, etc. are influenced to a large degree by the grain size. The author made this comparative study of methods in an attempt to determine how closely the several methods checked, and how they compare in simplicity of operation. Besides this comparison, the author also presents the effects of different electrolytes and the temperature and character of the water used.*

1. The purpose of the investigation reported in this paper was to make a comparative study of the more widely known and used wet methods for determining the fine-sized particles of clays, molding sands, soils, and other fine-grained natural or artificial substances.

2. Special attention was given to molding sands due to the fact that their grain size is their most important single property. All of the other properties of molding sands, such as strength, permeability, etc. are influenced to a large degree by this factor.

3. One object in view in making these comparisons was to determine how closely the several test methods checked, and how they compare in simplicity of operation.

4. In addition to making a comparative study of the several methods, attention was also given to the effect of different electrolytes and the temperature and character of the water used.

* Geology Department, Cornell University.

Note: This paper was presented at the session on Sand Control and Research at the 1934 Convention of the A.F.A.

## THEORY

5. All the "wet" methods of mechanical analysis are based upon Stokes law [1*] which states: when a small body is allowed to fall freely in a liquid medium, it soon reaches a constant velocity. At this point, the downward acceleration is balanced by the friction of the particle on the medium, therefore the velocity ceases to increase. This limiting velocity expressed mathematically is:

$$V = \frac{2g\,(a - b)\,R^2}{9c}$$

Where: V—Velocity of fall
g—Acceleration of gravity
a—Density of the falling substance
b—Density of the liquid medium
c—Viscosity of the liquid medium
R—Radius of the particle

6. However, in mechanical analyses the time required for a particle of known size to fall a given distance is of more value. The equation thus reduces to:

$$T = \frac{H}{V} = \frac{9\,Hc}{2g\,(a - b)\,R^2} \text{ or } T = \frac{H}{KR^2}$$

Where: T—Time of fall
H—Height of fall
K—Constant

7. The constant K has been determined by Krumbein[2] to be $3.57 \times 10^4$ at 20 degrees Cent., with the assumption that the gravity of the sample is 2.65.

8. From these equations we can see that if a known weight of material is suspended in a fluid medium of known depth for a definite period of time, the weight and grain size of the suspended material can be determined by some suitable sampling procedure. All of the methods for the mechanical analysis of fine particles that will be discussed are based upon this principle.

## METHODS EMPLOYED

9. The methods used for the separation of fine particles in molding sands, soils, and clays are, with few exceptions, wet methods and may be divided into the following groups:

(1) *Elutriation Method:* In which the particles

* Superior numbers refer to bibliography at end of paper.

are separated into their respective grain sizes by a rising current of water of controlled velocity.

(2) *Pipette Method:* In which a known volume of a suspension is taken from a definite depth below the surface, at definite time intervals, the weight of the suspended material determined, and the grain size calculated.

(3) *Manometer Method:* A manometric method in which the weight of a soil suspension is balanced against that of a column of clear water.

(4) *Method of the American Foundrymen's Association:* A sedimentary or settling method.

(5) *Hydrometer Method:* In which the grain size is determined or calculated from the density of the solution, determined at definite intervals.

10. Each of the above methods will be described and their apparent advantages or disadvantages pointed out.

## PREPARATION OF THE SAMPLE

11. Before any sediment can be subjected to mechanical analysis, it must be thoroughly dispersed in some fluid medium. The purpose of this dispersion is to break existing aggregates into individual particles. Should well cemented compound grains be present, it is not desirable, from the foundrymen's point of view, to break these up.

12. The disintegration[16] of the sand or clay may be done in a rotating shaker[3], a mechanical stirrer[3], by boiling[4], or by dispersion with steam[5].

13. The rotating shaker method is very satisfactory, but it requires an hour or more for operation.

14. The stirrer method is very rapid, not taking more than ten minutes for complete dispersion of a clayey sand, but care must be taken to have good baffles in the stirring receptacle. In using this apparatus for dispersion, a hard metal or alloy should be used for the rotor disk, as sand grains rapidly wear a soft disk down, with a marked loss in efficiency.

15. Boiling[4] has been recommended by several investigators, the general procedure being to heat the sample for ten minutes with a suitable electrolyte at the boiling point.

16. Agitation[5] with a jet of live steam under 30 lbs. pressure for ten minutes is a recent suggestion.

17. The finest material in molding sands, clays, soils etc. is of colloidal size and therefore behaves according to the laws which govern such bodies.

18. Colloidal particles when dispersed in a fluid medium are electrically charged[6, 8], the charge in the case of clay being a negative one. By acquiring and holding this common charge the colloidal particles repel each other, thus breaking down aggregates and allowing the particles to act as individuals. The degree to which a given sample is dispersed depends upon the ability of the electrolyte added to the liquid medium to supply the common charges needed.

### DISCUSSES ELECTROLYTES

19. To supply these negative charges or anions, a number of substances have been recommended by various authors. Which of these dispersing agents will give the best results with a given sample cannot be foretold with any degree of accuracy as the physical and chemical nature of colloids is a variable one and the behavior of each individual a specific one.

20. In the A.F.A. fineness test[3], sodium hydroxide has been recommended. Its advantage lies in the fact that the amount and concentration of the solution used has been standardized and thus consistently comparable results can be obtained.

21. The British Cast Iron Research Association recommends the use of ammonium hydroxide[4].

22. Casagrande[7] and the Bureau of Public Roads employ sodium silicate, while Galliher[8] advocates sodium citrate or sodium oxalate. The Bureau of Soils[9], the Bureau of Standards[10], Krumbein[2] and others recommend the use of sodium oxalate.

23. Krumbein[2] and others have also used sodium carbonate with success.

24. To determine the effect of some of these electrolytes on molding sands the author tried sodium hydroxide, sodium oxalate, sodium carbonate, sodium silicate, and ammonium hydroxide.

25. The sands used were:

No. 1; Devine sand from New Jersey, Whitehead Bros.

No. 2; King sand, Albany N. Y., Whitehead Bros.

No. 3; Black Hawk sand, Rockton, Ill.

26. Table 1 shows the results obtained using different electrolytes on these sands.

27. The effect of the various electrolytes on Sand No. 1 shows very little difference, but in the case of the Albany sand, No. 2, the different electrolytes and the percentage of each used has a marked effect on the amount of A.F.A. clay obtained.

28. In the case of the Illinois sand, it was found that 1 per cent and 3 per cent sodium hydroxide gave consistent results, but that when 5 per cent of the electrolyte was used, the sample refused to disperse. This same curious result was noted with the sodium oxalate solution.

29. It should also be noted that the Albany sand gave consistently higher percentages of clay substance with the higher percentages of electrolyte.

30. This points out the fact that if two persons are trying to check each other's results, they should use the same elctrolyte and the same amount of it.

31. Saunders[20] has also shown that increasing the amount of electrolyte may, in some cases, increase the amount of clay substance. The most striking instance of this was a sand from

**Table 1**

INFLUENCE OF ELECTROLYTES ON CLAY SUBSTANCE DETERMINATION

| Sand | Electrolyte | Percent and Volume used | A.F.A. Clay Substance % |
|---|---|---|---|
| Sand No. 1 | NaOH | 25cc.—1% | 43.30 |
| | | | 43.26 |
| (Devine, N. J.) | NaOH | 25cc.—5% | 43.38 |
| | | | 43.41 |
| | $Na_2C_2O_4$ | 25cc.—1% | 43.00 |
| | | | 43.05 |
| | $Na_2C_2O_4$ | 25cc.—5% | 43.40 |
| | | | 43.42 |
| | $NH_4OH$ | 25cc.—1% | 43.00 |
| | | | 43.10 |
| | $NH_4OH$ | 25cc.—5% | 43.21 |
| | | | 43.25 |
| | $Na_2Si_4O_9$ | 25cc.—1% | 42.92 |
| | | | 42.89 |
| | $Na_2Si_4O_9$ | 25cc.—5% | 43.17 |
| | | | 43.10 |
| | $Na_2CO_3$ | 25cc.—1% | 43.30 |
| | | | 43.26 |
| | $Na_2CO_3$ | 25cc.—5% | 43.40 |
| | | | 43.39 |
| Sand No. 2 (King, Albany, N. Y.) | NaOH | 25cc.—1% | 21.81 |
| | | | 21.83 |
| | NaOH | 25cc.—5% | 22.79 |
| | | | 22.81 |
| | $Na_2C_2O_4$ | 25cc.—1% | 21.45 |
| | | | 21.51 |
| | $Na_2C_2O_4$ | 25cc.—5% | 22.68 |
| | | | 22.60 |
| | $NH_4OH$ | 22cc.—1% | 21.30 |
| | | | 21.28 |
| | $NH_4OH$ | 25cc.—5% | 21.72 |
| | | | 21.69 |
| | $Na_2Si_4O_9$ | 25cc.—1% | 20.33 |
| | | | 20.35 |
| | $Na_2Si_4O_9$ | 25cc.—5% | 20.55 |
| | | | 20.55 |
| Sand No. 3 (Black Hawk, Rockton, Ill.) | NaOH | 25cc.—1% | 21.66 |
| | | | 21.63 |
| | NaOH | 25cc.—3% | 21.85 |
| | | | 21.90 |
| | NaOH | 25cc.—5% | Flocculated |

Coosada, Alabama, where increasing the amount of sodium hydroxide added from 25 to 1,000 mg. increased the clay substance obtained from 19.0 to 34.8 per cent.

32. Krumbein[16] found in some experiments with a calcareous clay, that sodium oxalate gave a greater dispersion than sodium carbonate, and hence would give a higher clay content.

33. Galliher[8], suggests that sodium oxalate and sodium citrate are more efficient dispersing agents than ammonium hydroxide.

34. However, attention should be called to the fact that the dispersing power of any given electrolyte will depend upon the character of the colloids. It may also be affected by the acidity of the sand.

### EFFECT OF TEMPERATURE

35. The change in the density of the fluid medium with small changes in temperature is so small that it can be neglected in mechanical analyses, but the change in the viscosity of the medium with changes in temperature is an important consideration. The Pipette, Casagrande, Bureau of Standards and the Bouyoucos methods give a correction for this factor, but the

**Table 2**

EFFECT OF TEMPERATURE ON CLAY SUBSTANCE.

| | Temperature, Degrees C. | Percentage of A.F.A. Clay Substance | | Temperature, Degrees C. | Percentage of A.F.A. Clay Substance |
|---|---|---|---|---|---|
| Sand No. 1 | | | Sand No. 2 (Continued) | | |
| | 15 | 45.82 | | 18 | 22.22 |
| | 15 | 45.72 | | 18 | 22.20 |
| | 17 | 44.66 | | 20 | 21.81 |
| | 17 | 44.60 | | 20 | 21.83 |
| | 20 | 43.30 | | 25 | 20.65 |
| | 20 | 43.26 | | 25 | 20.56 |
| | 25 | 40.67 | | 30 | 19.75 |
| | 25 | 40.51 | | 30 | 19.81 |
| | | | Sand No. 3[19] | | |
| | 29 | 39.40 | | 20 | 12.06 |
| | 29 | 39.33 | | 20 | 12.04 |
| Sand No. 2 | | | | | |
| | 15 | 23.11 | | 26 | 11.15 |
| | 15 | 22.95 | | 26 | 11.22 |
| | | | | 30 | 10.68 |

**Table 3**

Effect of Different Kinds of Water on Clay-Substance Tests

| Sand | NaOH Electrolyte Concentration, Per Cent (25cc. in 475cc, water) | Per Cent Clay Substance | |
|---|---|---|---|
| | | Tap Water | Distilled Water |
| No. 1 | 1 | 39.34 | 43.30 |
| | 1 | 38.71 | 43.26 |
| | 5 | 40.66 | 43.38 |
| | 5 | 40.17 | 43.41 |
| No. 2 | 1 | 18.71 | 21.81 |
| | 1 | 17.99 | 21.83 |
| | 5 | 19.11 | 22.79 |
| | 5 | 19.71 | 22.81 |
| | 5 | 19.21 | |
| | 5 | 18.89 | |

A.F.A. and Elutriation methods entirely disregard it. Table 2 shows the effect of temperature on the percentage of A.F.A. clay substance determined.

36. In the tests in Table 2, sodium hydroxide was used as an electrolyte, 25 cc. being added to 475 cc. of distilled water.

## Character of the Water Affects Test

37. The character of the water used in mechanical analyses is an important point. Tap water invariably gives different results than those obtained with distilled water. Even different distilled waters may cause a variation in the results obtained. Table 3 will bring out this point. It can be clearly seen that the results differ greatly, especially in the case of the Albany sand (No. 2).

38. To overcome, if possible, the effects of tap water on the suspended material a series of experiments were run using tap water, but on every washing 5 cc. of the electrolyte were added. The results are shown in Table 4. Although this procedure did stabilize the results, the percentages obtained never equaled those obtained with distilled water. Clay determinations were made by the A.F.A. method.

## Description of Methods

*Pipette Method.*[2, 9, 10, 11]

39. The principle[11] of this method is based upon the fact that a sample of a suspension taken at a predetermined depth, X,

**Table 4**

RESULTS USING TAP WATER AND ADDING 5CC. OF THE ELECTROLYTE WITH EACH SIPHONING

| Sand | NaOH Electrolyte Concentration, Per Cent (25cc. in 475cc. water) | Per Cent Clay Substance | |
|---|---|---|---|
| | | Tap Water Plus 5cc. of Electrolyte | Distilled Water |
| No. 1 | 1 | 42.81 | 43.30 |
| | 1 | 42.96 | 43.26 |
| | 5 | 43.03 | 43.38 |
| | 5 | 43.12 | 43.41 |
| No. 2 | 1 | 20.33 | 21.81 |
| | 1 | 20.16 | 21.83 |
| | 5 | 21.77 | 22.79 |
| | 5 | 21.86 | 22.81 |

and time, T, by means of a calibrated pipette will contain no particles whose settling velocities exceed $\frac{X}{T}$. Hence, all particles with a smaller settling velocity are present in the sample in the same concentration as in the original suspension. The sample drawn off is evaporated and weighed. By knowing the capacity of the pipette, this weight can be expressed as a concentration whose percentage ratio to the original concentration of the suspension gives the percentage weight of the particles with a velocity less than $\frac{X}{T}$. The suspension may be agitated again and another sample taken at another critical velocity, and so on until the desired separation is effected.

40. A brief outline of the procedure is as follows: A sample of known weight is dispersed. The dispersed sample is transferred to a 1000 cc. graduated cylinder and sufficient distilled water is added to bring the volume to the 1 liter mark. A uniform dispersion is then obtained by placing the palm of the left hand over the mouth of the cylinder and inverting the latter, end on end, for a period of one minute. The moment the cylinder is placed on the table a stop watch is started.

41. One minute and 55 seconds[2] later, 20 cc. of the suspension is drawn off at a depth of exactly 10 cm. below the surface of the suspension. The contents of the pipette are emptied into a weighed dish and evaporated at about 105 degrees Cent. The weight of the residue is determined, a correction being made for

the percentage of electrolyte present, and the result multiplied by 50. This gives the total weight of the material finer than 0.031 mm., in the sample.

42. In the meantime, the sample is shaken again and allowed to stand for 7 minutes and 40 seconds. Then another 20 cc. is drawn off as before, evaporated and its weight determined. The resulting weight is the material finer than 0.015 mm. By subtracting the weight of the second from the first, the weight of the material in the 0.031-0.015 mm. size class is found. The process is repeated using the intervals and depths given in Table 5 until the desired separation is effected.

43. For determining A.F.A. clay content by this method, Saeger has outlined the following procedure[10]. He has drawn a curve showing the settling time of a particle 20 microns in diameter at a depth of 5 inches below the surface in relation to the time. An accurate determination of the A.F.A. clay substance can be made by using this curve in connection with the pipette method.

44. The advantage of the pipette method is high accuracy, especially in determining the grain size of the finer particles.

45. The disadvantages are: (1) time consumed in making an analysis, and (2) the calculations and temperature corrections are laborious.

### Elutriation Method[4, 12]

46. The elutriation method is based upon the principle that a rising stream of liquid containing particles in suspension will carry upward those whose falling velocity is less than that of the current, while those having a higher settling velocity will move downward against the stream. By regulating the velocity of the liquid, a grain size separation can be effected.

47. A great number of elutriators of different types are used

**Table 5**

Time and Diameter of Particles

| Time | | | Depth in Cm. At Which Sample Taken | Diameter of Particles in mm. |
|---|---|---|---|---|
| Hrs | Min. | Sec. | | |
| | 1 | 55 | 10 | 0.031 |
| | 7 | 40 | 10 | 0.015 |
| | 30 | 40 | 10 | 0.0078 |
| 1 | 14 | 40 | 10 | 0.0050 |
| 2 | 2 | 40 | 10 | 0.0039 |
| 8 | 10 | 40 | 10 | 0.00199 |

Some, like the Treuheit[18] and Nipper[17] apparatus, consist of a series of chambers arranged in order of increasing diameters. A current of water passing from one of the smaller receptacles to one of the larger ones slows down. The larger grains therefore

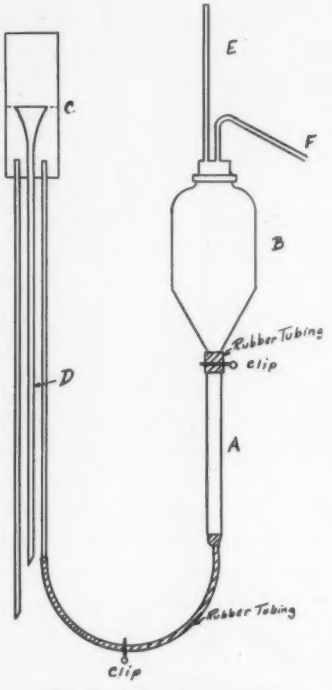


FIG. 1—CROOK ELUTRIATOR.

settle out in the small receptacles, the finer material in the larger ones, while the very fine material or clay is carried off.

48. The most widely used types are those developed by Boswell[4], and Crook[4]. As these two pieces of apparatus differ in only a few minor details, a description of one will suffice.

*Crook Apparatus.*

49. The Crook[4] elutriator, shown in Fig. 1, consists essentially of two cylinders, a narrow one *A*, and an upper broader one *B*. In order to obtain a constant rate of flow upward through these cylinders, a small movable reservoir *C* is used with an over-

flow funnel and tube *D*. The movable reservoir *C* can be raised or lowered, and a constant head and pressure of water may be obtained in the apparatus. The vessel *B* is fitted with a double holed stopper through which passes a straight tube *E* which acts as a manometer, and a bent tube *F* with a jet at the end. The velocity of the water in *A* and *B* is regulated by the size of the jet opening, and by adjustment of *C*. The velocity is indicated by the height to which the water rises in *E*. The lower portion of *B* and the tube *A* should be the same diameter and joined by rubber tubing of the same internal diameter, and fitted with a clip. Another clip is used to cut *A* off from *C*. The ratio of the size of *A* to *B* should be close to 50-1.

50. A weighed quantity of molding sand etc. (10 or 20 grams) is dispersed and placed in *B*. The clips are released and the water is allowed to flow until it runs clear at the nozzle *F*. The clip between *A* and *B* is inserted, and the connection between *A* and *C* is closed. The weight of the material in *A* is the sand in the sample, while the weight of the material in *B* gives the silt content. The difference between *A* plus *B* and the weight of the original sample gives the percentage of clay.

51. The internal diameters of the various parts are as follows:

*A*, 1.4 cm., upward velocity— 7 mm/sec.
*B*, 9.8 cm., upward velocity—0.15 mm/sec.
Jet—1 mm.

*Wisconsin Apparatus*

52. Two years ago a similar apparatus was constructed and tested at the University of Wisconsin[12]. In the published description, a comparison was made of this elutriator and the A.F.A. method. Although greater accuracy was claimed for the former and duplicate determinations given for clay checked very closely, the author has found it difficult to obtain accurate results with this apparatus. Furthermore, the comparative figures given for determinations by the A.F.A. method show much greater differences on duplicate tests, than are justified if a little care is used. It was also found difficult to adjust the rate of flow, and to maintain it in consecutive tests.

53. The apparatus, shown in Fig. 2, consists of a long type separatory funnel *A* of 1500 cc. capacity; a siphoning tube *B*, approximately ¼ inch inside diameter, touching the surface of

the water ¼ inch from the funnel wall at the widest part. The valve *E* in tube *C* is for controlling the air inflow and acts as a pressure indicator. The bottom of tube *C* should be level with the intake of siphoning tube *B*.

54. The attachment is for controlling the water pressure. This constant pressure device should be adjusted so that when

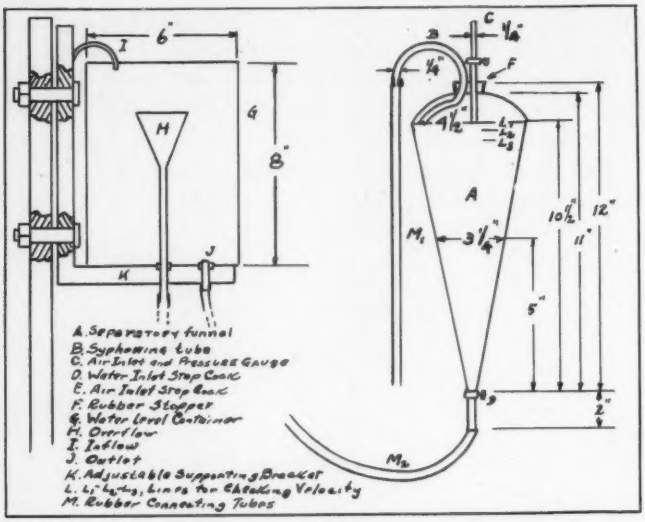


FIG. 2—(LEFT)—PRESSURE TANK FOR WISCONSIN ELUTRIATOR. (RIGHT)—WISCONSIN ELUTRIATOR.

valve *D* is wide open, the surface of the water will be rising at a rate of 1 inch per minute when it reaches the widest part of the funnel. Three lines $L_1$, $L_2$, and $L_3$, spaced ½ inch apart, permit the measurement of this velocity.

55. After the water pressure has been adjusted for the correct velocity, a sample of dispersed material is placed in the funnel with the lower valve *D* closed. The valve is then opened until the funnel becomes about two-thirds filled with water and it is then closed, until nearly all the sand has settled to the bottom. The valve is then opened wide and the sand washed until the water above it is clear.

56. When it is clear, the valve *D* is closed and the sand removed from the funnel either by removing the rubber stopper containing *B* and *C* and inverting the funnel, or by removing the

rubber connection at *D* and washing the sand grains through that opening into some suitable receptacle.

57. The sand is dried and weighed. This weight subtracted from the weight of the original sample gives the weight of the material with a settling rate greater than 1 inch per minute, or the A.F.A. "Clay Substance".

58. The advantage of the elutriation method is speed in determining A.F.A. clay substance.

59. The disadvantages of the method are:

(1) Tap water is used, and consequently it is difficult to regulate its temperature. Moreover it may exert a marked effect on the colloidal material present, as the inflowing water rapidly removes the electrolyte.

(2) No correction is made for the temperature of the water.

(3) The velocity distribution across the stream is not a straight one, but parabolic.

(4) In the separation of the larger size particles, the flow changes from a viscous to a turbulent one.

(5) In the case of the Wisconsin apparatus, the difficulty of adjustment and operation, especially of the stop cocks, far overbalances any good features that it might have.

### A.F.A. METHOD

60. The A.F.A. method[3] is a sedimentation one; that is, it is based on the fact that the larger particles in a suspension settle out more rapidly than the smaller ones.

61. The general procedure is to disperse a known sample in distilled water, using 25cc. of a 1 per cent NaOH solution as the electrolyte. After dispersion, the suspension is transferred to a suitable receptacle, agitated and allowed to stand 10 minutes. The suspension is siphoned off to a depth of 5 inches below the level to which the jar had been filled. The container is refilled to the original mark and at the end of 10 minutes the water is again drawn off to a depth of 5 inches below the original surface of the water. From then on, 5 minute settling and siphoning periods are inaugurated and are repeated until the water is clear to a depth of 5 inches below the surface. The material remaining in the jar is washed out, dried and weighed. The difference between the weight of the residual material and the weight of the

original sample gives the weight of the material which had a settling rate of less than 1 inch per minute. This is defined as "clay substance".

62. It has been found that, with some sands at least, fewer washings are necessary to remove the clay when distilled water is used, as in Table 6.

63. The advantages of this method are:

(1) Extreme simplicity of operation and consistency of results. Very close check determinations can be made with a little care.

(2) The method has another advantage in that the whole apparatus and procedure is rigidly standardized.

64. If the apparatus has any disadvantages, they are:

(1) No separation is made between fine silt and clay, the two being determined as one. This is not necessarily to be regarded as a disadvantage, because in

**Table 6**

EFFECT OF WATER ON DETERMINATION OF CLAY SUBSTANCE

| Sand | No. of Washings | Water | NaOH % | Temp. °C. | Clay % | Clay % | Remarks |
|---|---|---|---|---|---|---|---|
| Devine | 13 | Dist.* | 5 | 20 | 43.45 | 43.50 | Clear |
| " | 13 | Dist.* | 1 | 20 | 43.06 | 43.12 | Clear |
| " | 13 | Dist. | 5 | 19 | 43.38 | 43.41 | Clear |
| " | 13-14 | Dist. | 1 | 19 | 43.30 | 43.26 | Clear |
| " | 24 | Tap | 5 | 17 | 41.71 | 40.67 | Slightly Turbid |
| " | 25 | Tap | 1 | 17 | 40.41 | 40.17 | Slightly Turbid |
| " | 17 | Tap | 5 | 17 | 42.81 | 42.96 | 5cc. NaOH Each Washing |
| " | 18 | Tap | 1 | 17 | 42.70 | 42.75 | 5cc. NaOH E. W. |
| " | 14 | Dist. | 5 | 10 | 46.95 | 47.03 | Clear |
| " | 14 | Dist. | 1 | 10 | 46.60 | 46.48 | Clear |
| " | 13 | Dist. | 5 | 29 | 40.01 | 39.86 | Clear |
| " | 14 | Dist. | 1 | 29 | 39.40 | 39.33 | Clear |
| " | 14 | Dist. | 5 | 19 | 43.42 | 43.46 | Clear |
| " | 14 | Dist. | 1 | 19 | 43.00 | 43.05 | Clear |
| " | 13 | Dist.* | 5 | 19 | 43.41 | 43.48 | Clear |
| " | 14 | Dist.* | 1 | 19 | 43.34 | 43.24 | Clear |
| King | 11 | Dist. | 5 | 19 | 22.79 | 22.81 | Clear |
| " | 11 | Dist. | 1 | 19 | 21.81 | 21.83 | Clear |
| " | 11 | Dist. | 5 | 19 | 22.68 | 22.60 | Clear |
| " | 12 | Dist. | 1 | 20 | 21.45 | 21.51 | Clear |
| " | 27 | Tap | 5 | 18 | 19 11 | 19.71 | Turbid |
| " | 29 | Tap | 1 | 17 | 18.71 | 17.99 | Turbid |
| " | 27 | Tap | 5 | 17 | 18.99 | 19.21 | Turbid |
| " | 28 | Tap | 1 | 17 | 17.80 | 18.51 | Turbid |
| " | 12 | Dist.* | 5 | 20 | 23.06 | 23.14 | Clear |
| " | 12 | Dist.* | 1 | 20 | 22.21 | 22.11 | Clear |

*In all cases except those marked, the separation of clay was made immediately after the sample was disintegrated. Cases marked * stood for 24 hours.

foundry work it is still to be determined to what extent fine silt and clay behave differently.

(2) As carried out at present, no attention is paid to the effect of temperature on the viscosity of the water.

65. A method for a rapid determination of "true clay" in connection with this method will be outlined under a later heading.

## MANOMETER METHOD*

66. This method is a modification proposed by the Bureau of Standards, of an earlier procedure.[21, 22]

67. As stated before, the principle upon which this method[13] is based is a manometric one, that is, that the additional pressure exerted by a column of water due to the fine particles suspended in it is measured by a delicate manometer. As the particles settle out of the suspension the pressure decreases, and their grain size and per cent of same can be calculated or determined from a curve based on the amount of recession of the column of water in the manometer, the time elapsed, and the height of the sedimentation tube. Perhaps the best way to explain the mechanism of this apparatus is through a description.

### *Apparatus*

68. The apparatus shown in Fig. 3 is essentially an upright U tube. The larger arm is 3 cm. diameter, 140 cm. long, and is extended 15 cm. beyond the smaller one. It is tapered to fit a hole in a rubber stopper which closes the mouth of a pint fruit jar. The smaller arm of the U-tube is 100 cm. long, and is attached to the larger tube by a two way stop cock. To increase the sensitivity of the movement of the column of water in the smaller arm, a glass tube of 2 mm. internal diameter, and 60 cm. long is attached to the upper end of this arm in a sloping position. A conveniently placed metric scale is used to obtain the readings of the manometer tube[2]. A means of draining the apparatus is shown in the figure. The whole assembly is clamped to a stand.

69. The apparatus is filled with distilled water and the height of the liquid will be the same in both arms. Now if a portion of the water in $X$ is replaced by heavier material, sand grains etc., the liquid will rise in $Y$ and $Z$ and will remain higher until the

* The data relating to this method were kindly supplied by C. M. Saeger, Jr. of the Bureau of Standards, with permission to publish. The modified method as here described was developed by C. E. Jackson.

particles have settled below the point *O*. The rate of fall of the suspended particles in *X* is determined by their effective diameters. The recession of the column of liquid in *Z* supplies a means of studying the distribution of effective particle size of the suspended material.

70. A 10 gram sample of material is used in the tests, the

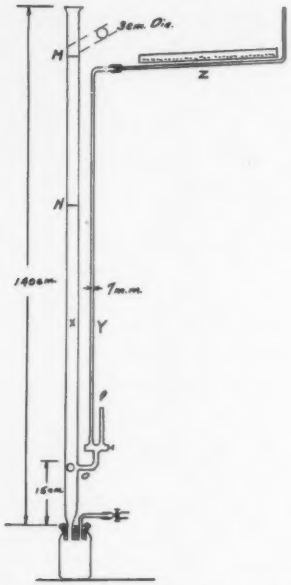


FIG. 3—MANOMETER METHOD APPARATUS.

specific gravity being taken as 2.65. Such a sample has a volume of 10/2.65 or 3.77 cc. Due to the buoyancy of the water, a 10 gram sample can be considered as equivalent in effect to only 10 — 3.77 or 6.23 grams.

*Test procedure*

71. The apparatus with the stop cock open into *Y* is filled to the level *M* with distilled water. As soon as equilibrium is reached, the reading of the index in *Z* is taken. Ten cc. of water are then added to the water in *X*. The resulting rise in *Z* is divided by 10 and is the calibration constant of the test. Since the 10 gram sample is equivalent to only 6.23 grams, the manometer

is drained to a level 6.23 times the calibration constant above the zero reading. The stop cock *Y* is closed and the water in tube *X* is drained to level *N*, 38 cm. below *M*.

72. A 10 gram sample is then dispersed in the usual manner in 200 cc. of distilled water. At the start of a stop watch, the suspension is poured into *X* and the level carefully adjusted to *M* by allowing water to flow out at *P* through the stop cock. The stop cock is then turned so that the passage to *Y* is open, and readings on the manometer are taken at 40, 50, 60, 90, 120, 150, 180 seconds, and 4, 5, 6, 7, 8, 9, 10, 15, 20, 30, and 60 minutes.

*Calculation.*

73. To calculate the percentage and grain size of the suspended material from the manometer readings, the following procedure is used.

74. The difference between the corrected reading in *Z* at the start of the test, and the zero reading in *Z* is found. The recession in the manometer tube at any given time is divided by the factor found previously, and the resulting figure multiplied by 100. This percentage is the per cent of the material that has settled out in the elapsed period of time used. To find the grain size a curve, shown in Fig. 4, is used. To correct for temperatures above or below 20 degrees Cent., the manometer readings are multiplied by the ratio of the viscosity of the water at the time of the test, to the viscosity of the water at 20 degrees.

75. Advantages of this method:

(1) It is a rapid one, an analysis being made in about 2 hours.

(2) The results obtained are consistent and check with those obtained with other methods.

76. The disadvantages are:

(1) The apparatus is difficult to operate.

(2) It requires a delicate, although not expensive apparatus.

## Hydrometer Methods[7, 15, 14]

77. The hydrometer[7] methods are based upon the fact that a particle falling through a liquid medium quickly assumes a uniform settling rate, and when this velocity is constant the medium through which it is falling must exert a frictional resistance on the particle equal to its weight. Therefore the particle must

cause a local pressure in the liquid surrounding it, and in the liquid beneath it.

78. If a great number of particles are distributed in the liquid and are dropping at different rates, the medium will exert a hydrostatic pressure which at a given point is equal to the weight of the suspension above. Therefore, the hydrostatic uplift on a hydrometer immersed in such a suspension is equal to the weight of the displaced suspension at the same elevation and therefore measures the average density over the height of its bulb.

79. Working on these hypotheses, several methods of deter-

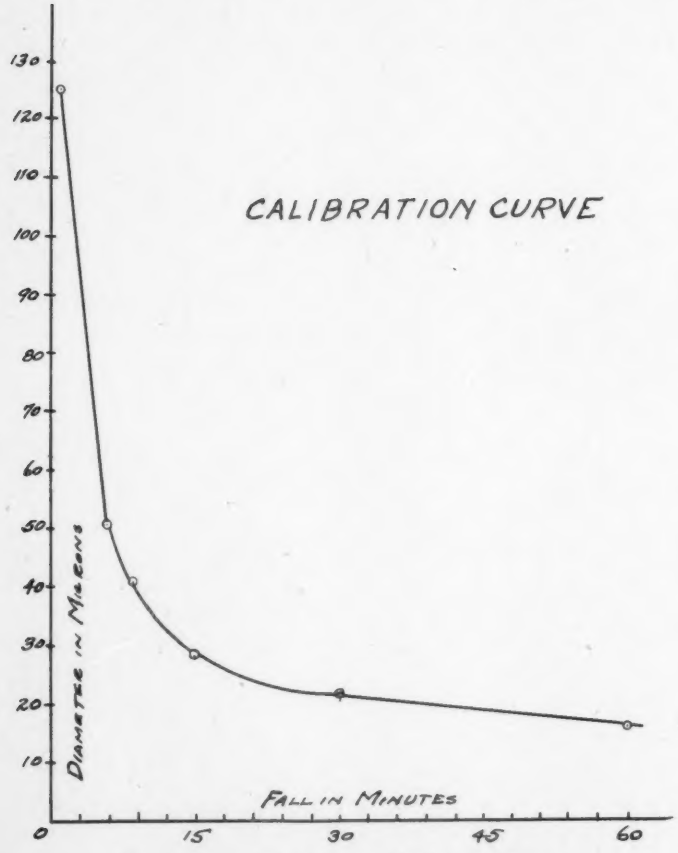


FIG. 4—GRAIN SIZE CURVE FOR MANOMETER METHOD.

mining the grain size of various suspensions have been devised. Two will be taken up briefly in the following paragraphs.

*Bouyoucos Method.*[14, 15]

80. In this method the only special apparatus required, is a Bouyoucos hydrometer which is calibrated in grams of soil per liter, and a special sedimentation cylinder with two graduations on it. The lower one is used with a suspension containing 50 grams of soil per liter, the upper one with a suspension containing 100 grams.

81. *Procedure:* A soil suspension is prepared, preferably by disintegration in a stirrer, and placed in the sedimentation cylinder. Water is added to bring the suspension up to the proper mark. It is then vigorously shaken for a period of one minute by placing the palm of the left hand over the mouth of the cylinder and inverting end for end. The moment the cylinder is placed on the table a stop watch is started.

82. The hydrometer is slowly lowered into the suspension and a reading is taken at the end of 40 seconds. The hydrometer is removed, washed, and dried. Additional readings are taken after the elapsed time intervals of 15 minutes, 1 hour and 2 hours. The temperature of the suspension is taken at the end of every reading. For every degree over 67 degrees Fahr. a correction of 0.2 graduation on the hydrometer is added to the hydrometer reading. For every degree under 67 degrees Fahr. a similar correction is subtracted from the hydrometer reading.

83. *Determination of grain size and percentages:* The corrected hydrometer reading at the end of 40 seconds is divided by the weight of the original sample and multiplied by 100. This result gives the percentage of sand in the sample. The corrected hydrometer reading at the end of 15 minutes is also divided by the weight of the sample and multiplied by 100. The resulting percentage is the amount of material still in suspension or the "total colloidal" content of the sample. The corrected hydrometer reading at the end of one hour is also divided by the weight of the sample and multiplied by 100, this percentage giving the percentage of clay in the sample. The percentage of silt is found by subtracting the percentage of clay from 100, and from this result subtracting the percentage of sand. The corrected hydrometer reading at the end of two hours is divided by the weight of the original sample and multiplied by 100, the resulting percentage is the "finer" clay in the sample.

84. The ranges of the grain size classes differentiated by this method are:

Sand ..... (1.0-0.05 mm)
Silt ..... (0.05-0.005 mm)
Clay ..... (0.005-000 mm)
Finer Clay..... (0.002-000 mm)

85. The advantages of this method are:

(1) Rapid and simple to manipulate. The personal equation is at a minimum.

(2) Reasonably accurate when used under the proper conditions.

86. The disadvantages are:

(1) For accurate scientific work the temperature correction of 0.2 graduations per degree above or below 67 degrees Fahr. is not sufficiently exact. From the foundryman's point of view, however, this objection is not a serious one, as his clay determinations need not be of the same degree of accuracy as those for scientific purposes.

(2) The range between 0 and 10 grams per liter is not as accurate as the rest of the scale, for this range reads about 1 gram too high. Therefore it is necessary to make this correction for all hydrometer readings below 9.9 grams per liter. This objection is a valid one from the viewpoint of the analysis of sands for foundry purposes, as a majority of them run well below 10 per cent true clay (100 gram sample).

87. The U. S. Bureau of Public Roads uses a special type of hydrometer with this method in order to minimize errors. They have also constructed charts for use in computing corrections for temperature, density, and viscosity of the medium, specific gravity of the solid particles, etc.[23]

*Casagrande Method.*[7]

88. The Casagrande method differs from the Bouyoucos method in that the hydrometer used is graduated in density instead of grams of soil per liter. The type recommended has a range of 0.995 to 1.040, with an accuracy of plus or minus 0.0002. The sedimentation cylinder is an ordinary 1000 cc. graduate with a minimum inside diameter of 2.36 inches.

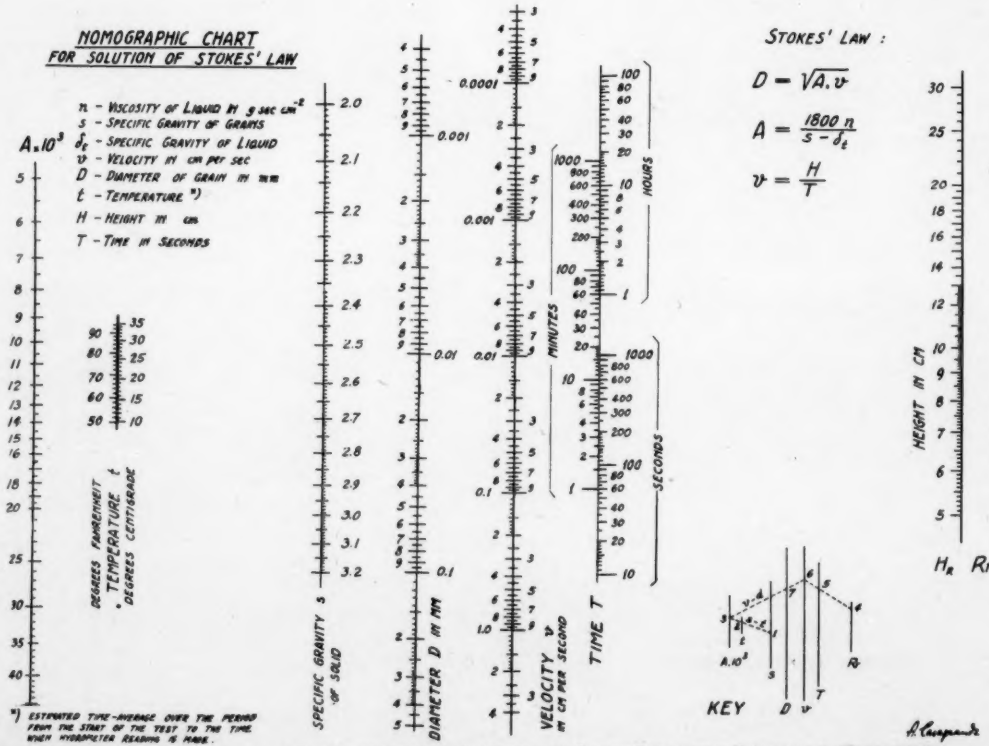
NOMOGRAPHIC CHART
FOR SOLUTION OF STOKES' LAW
η - VISCOSITY OF LIQUID IN g sec cm⁻²
s - SPECIFIC GRAVITY OF GRAINS
δt - SPECIFIC GRAVITY OF LIQUID
v - VELOCITY IN cm per sec
D - DIAMETER OF GRAIN IN mm
t - TEMPERATURE *)
H - HEIGHT IN cm
T - TIME IN SECONDS
A.10³
DEGREES FAHRENHEIT
• TEMPERATURE t
DEGREES CENTIGRADE
SPECIFIC GRAVITY s OF SOLID
DIAMETER D IN MM
VELOCITY v IN CM PER SECOND
TIME T
HOURS
MINUTES
SECONDS
*) ESTIMATED TIME-AVERAGE OVER THE PERIOD FROM THE START OF THE TEST TO THE TIME WHEN HYDROMETER READING IS MADE.
STOKES' LAW :
D = √A.v
A = 1800 η / (s - δt)
v = H/T
KEY
HEIGHT IN CM
HYDROMETER READING
Hr Rr
DESIGN OF (Rr)-SCALE :
READING
CENTER OF VOLUME OF BULB
HEIGHT Hr WHICH CORRESPONDS TO READING Rr DETERMINED FROM
Hr = H1 + ½(h - VOLUME OF HYDR. BULB / AREA OF GRADUATE)
CONSTANT
H TO BE DETERMINED FOR DIFFERENT VALUES OF Rr. CORRESPONDING VALUES OF Rr TO BE PLOTTED ON RIGHT SIDE OF (Hr)-SCALE AND CONVENIENT SUBDIVISIONS MADE.
FOR SOIL SUSPENSIONS IN WATER ANY HYDROMETER MEASURING DENSITIES BETWEEN 0.995 AND 1.060 WITH AN ACCURACY OF 0.0002 MAY BE USED.
SUGGESTED: CALIBRATION AT 20°C IN DENSITIES.
STREAM LINE BULB.
MAX H1 = 14 TO 16 CM
h = 15 TO 17 CM
FOR LIQUIDS OTHER THAN WATER THE (A)-VALUES MUST BE COMPUTED. THE (s) AND (t) SCALES APPLY ONLY TO SUSPENSIONS IN WATER.
A. Casagrande

FIG. 5—CHART FOR CALCULATING GRAIN SIZE FROM CASAGRANDE HYDROMETER.

89. *Procedure:* A sample of known weight is dispersed and placed in the glass cylinder. Water is added to bring the level of the suspension up to the 1000 cc. mark. It is agitated for one minute, using the same procedure as described under the Bouyoucos method. A stop watch is started the moment the cylinder is set upon the table, and the hydrometer is slowly inserted to a point

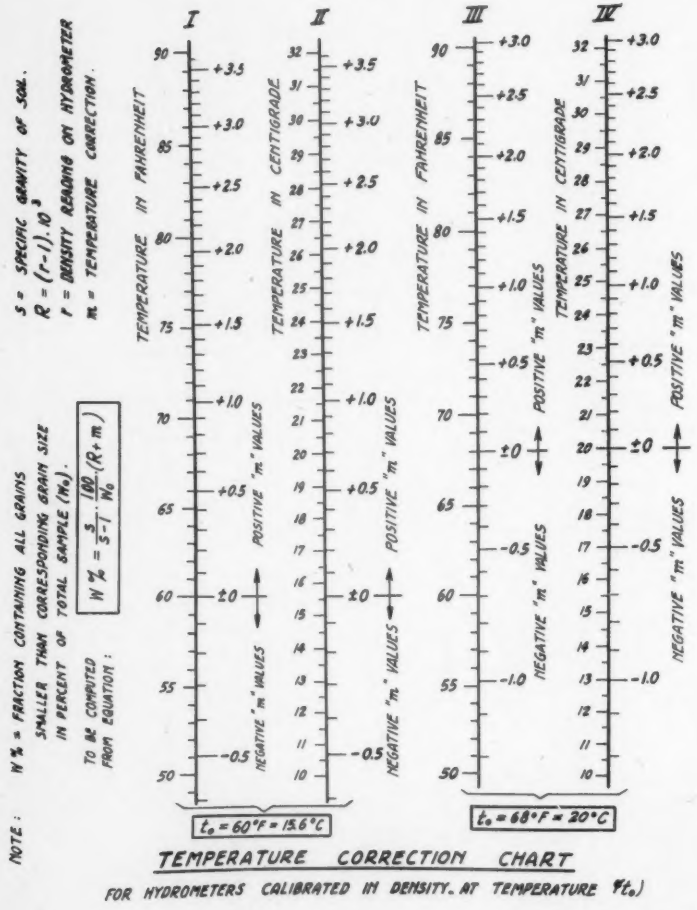
NOTE: W % = FRACTION CONTAINING ALL GRAINS SMALLER THAN CORRESPONDING GRAIN SIZE IN PERCENT OF TOTAL SAMPLE (Wo).
TO BE COMPUTED FROM EQUATION: W % = S/(S-1) · 100/Wo (R+m)
S = SPECIFIC GRAVITY OF SOIL.
R = (r-1).10³
r = DENSITY READING ON HYDROMETER
m = TEMPERATURE CORRECTION.
I
II
III
IV
TEMPERATURE IN FAHRENHEIT
TEMPERATURE IN CENTIGRADE
POSITIVE "m" VALUES
NEGATIVE "m" VALUES
to = 60°F = 15.6°C
to = 68°F = 20°C
TEMPERATURE CORRECTION CHART
FOR HYDROMETERS CALIBRATED IN DENSITY AT TEMPERATURE °(to)

FIG. 6—TEMPERATURE CORRECTION FOR CASAGRANDE HYDROMETER.

slightly below the level where it would float naturally, and then it is allowed to float freely.

90. Readings are taken after periods of ½ minute, 1 minute, and 2 minutes have elapsed. The hydrometer is removed, carefully cleaned, and dried. Additional readings are taken after 5 minutes, 15 minutes, 45 minutes, and 90 minutes have elapsed. Still more readings can be made, but the need for them depends upon the degree of differentiation of grain sizes desired. The temperature is taken during the first 15 minute period and after every reading thereafter.

*Calculations.*

91. The grain size is calculated or derived by the use of a nomographic chart,* shown in Fig. 5. The chart is used as follows:

(1) Determine the $A$ value by laying a ruler or some straight edge across the specific gravity and temperature values. The resulting value is noted.

(2) The straight edge is then placed on the $Rr$ value and the proper point on the time elapsed scale—this yields the velocity on the $V$ scale. This point is held with a pencil while the straight edge is turned around until it intersects the $A$ value previously determined. In this position the intersection with the $D$ scale gives the grain size.

(3) The temperature correction is taken from Fig. 6.

(4) The cumulative percentages are calculated from the equation:

$$\text{Per cent weight} = \frac{100}{\text{wt. of dry sample}} \times \frac{S}{S-1\ (Rm)}$$

S—Specific Gravity of the sample.

R—Hydrometer reading times 1000.

m—Temperature correction.

92. The advantages of this method are as follows:

(1) It has all the advantages of the other methods described plus speed and simplicity of operation.

(2) It can be applied to materials that are water soluble by using a different medium and hydrometer.

* Mr. Casagrande has kindly given permission to reproduce Figs. 5 and 6.

## COMPARISON OF METHODS

93. Table 7 gives the data of the comparison of the methods previously outlined. In all cases, a 1 per cent solution of sodium hydroxide was used as the dispersing agent. Distilled water was used in every case with the exception of the elutriation method where tap water was employed. All tests were made at temperatures between 19 and 20 degrees Cent.

94. It will be seen that the hydrometer, manometric and pipette methods check fairly closely on the true clay determination, but that the Wisconsin elutriator gave widely different and varying results.

95. The A.F.A. clay is a mixture of true clay and fine silt. The sum of the fine silt, very fine silt and true clay as determined by the Casagrande and Bureau of Standards methods, check approximately with the A.F.A. determination.

96. The procedure given for the pipette method does not subdivide the silts and hence makes comparison difficult.

97. The higher percentage of A. F. A. clay as determined by the elutriator for Sand No. 1 was due to the low temperature of the tap water used.

98. The much lower clay content determined by the elutriator for Sand No. 2 was due to fact that the material floculated towards the end of the test.

## COMBINATION A.F.A. AND HYDROMETER METHOD

99. In case it may be desired to determine the "true" clay content of a molding sand, the author has worked out a procedure for combining the Standard A.F.A. fineness test with the hydrometer method. It was found that little or no more time was consumed using this combination than would be required to run the usual A.F.A. analysis alone.

100. A 50 gram sample is prepared in the usual manner and is placed in a sedimentation cylinder. If the sample is known to run high in true clay substance the Bouyoucos cylinder is used, but if it is known to run low, the cylinder for the Casagrande method is employed. The suspension is uniformly distributed by the method previously described and a stop watch is started the moment the cylinder is placed on the table.

101. If the sand contains a large amount of clay substance, it is allowed to stand one hour, at the end of which period a reading is taken with the Bouyoucos hydrometer. The reading is cor-

rected for temperature and divided by 50, and the resulting figure multiplied by 100 gives the percentage of true clay present in the sample.

102. If the percentage of clay is small the suspension is allowed to stand 95 minutes, when a reading is taken with the Casagrande hydrometer, with additional readings at 100 and 105 minutes respectively. The grain size is found from the nomographic chart (Fig. 5) and the percentage of clay calculated.

103. From this point on, the procedure is the same for both types of sands: A glass siphon tube is inserted into the cylinder and the suspension drawn off to a depth 3 inches above the top of

**Table 7**

COMPARISON OF RESULTS OBTAINED BY DIFFERENT METHODS

| Method | Sand and Coarse Silt – – to 0.05 mm. | Medium Silt 0.05 to 0.02 mm. | Fine Silt 0.02 to 0.0075 mm. | Very Fine Silt 0.0075 to 0.005 mm. | Clay 0.005 to 000 mm. |
|---|---|---|---|---|---|
| | | | SAND No. 1 | | |
| Casagrande | 34.5 | 19.5 | 16.0 | 4.9 | 26.1 |
| | 35.1 | 19.2 | 15.7 | 4.0 | 26.0 |
| Bureau of Standards | 36.7 | 20.5 | 16.1 | | 26.7 |
| | 36.2 | 20.8 | 16.5 | | 26.4 |
| Bouyoucos | 38.8 | | 34.9 | | 26.3 |
| | 38.7 | | 35.4 | | 26.3 |
| Pipette | 36.4 | | 36.6 | | |
| | 35.9 | | 36.9 | | 27.0 |
| | | | | | 27.2 |
| A. F. A. | | 56.70 | | 43.30* | |
| | | 56.74 | | 43.26 | |
| Elutriation | | 52.54 | | 47.46* | |
| | | 54.69 | | 45.31 | |
| | | 55.63 | | 44.37 | |
| | | 51.21 | | 48.79 | |
| | | | SAND No. 2 | | |
| Casagrande | 44.0 | 32.9 | 11.4 | 1.0 | 10.9 |
| | 43.6 | 33.1 | 11.3 | 1.05 | 10.95 |
| Bureau of Standards | 47.7 | 29.59 | 11.91 | | 10.80 |
| | 47.1 | 30.33 | 11.82 | | 10.75 |
| Bouyoucos | 50.8 | | 38.7 | | 10.5 |
| | 51.3 | | 38.1 | | 10.6 |
| Pipette | 48.73 | | 40.16 | | 11.11 |
| | 49.35 | | 39.30 | | 11.35 |
| A. F. A. | | 78.19 | | 21.81* | |
| | | 78.14 | | 21.86 | |
| Elutriation | | 85.69 | | 14.31* | |
| | | 82.69 | | 17.51 | |
| | | 85.08 | | 14.92 | |
| | | 83.59 | | 16.41 | |

*A. F. A. Clay Substance.

the material in the bottom of the tube. The remaining contents of the cylinder are then washed into the A.F.A. sedimentation jar. From this point on, the procedure is the same as that outlined under the A.F.A. fineness test, except that only five minute washing periods are used.

104. Table No. 8 shows the results obtained by this modified method.

105. It will be noted from the above that no longer time is required to determine the true clay separately, as the number of washings required to treat the residue is greatly reduced.

## CONCLUSIONS

106. Different electrolytes may give different results. The effect of a given electrolyte canot be predicted as the behavior of colloids are specific.

107. It may be desirable to standardize on one electrolyte, thus insuring comparable results.

108. The temperature of the water is an important factor due its effect on the viscosity of the liquid medium.

109. It has already been recognized that there may be differences in results depending upon whether distilled or tap water was used.

110. Within certain limits the different types of apparatus described, with the exception of the elutriation method, give closely comparable results.

111. The A.F.A. apparatus is remarkable for its simplicity of operation and consistency of results. The main defect being

**Table 8**

TRUE CLAY CONTENT DETERMINED BY MODIFIED METHOD

| | Sand No. 1 (Bouyoucos) | Sand No. 2 (Casagrande) |
|---|---|---|
| Per cent of true clay first removed.... | 26.2 | 10.86 |
| | 26.3 | 10.88 |
| Per cent A. F. A. clay determined from remaining sample..... | 43.30 | 21.77 |
| | 43.25 | 21.79 |
| No. of additional siphonings required.. | 4 | 3–4 |
| Per cent A. F. A. clay determined by standard procedure..... | 43.30 | 21.81 |
| | 43.26 | 21.86 |
| No. of siphonings required..... | 14 | 12 |

that it does not separate fine silt and true clay. The author, however, has shown how the latter can be determined in an early stage of the analysis.

112. When distilled water cannot be obtained, it may be advisable to add small amounts of the original electrolyte to the water in every washing after the first one, when following the A.F.A. procedure.

113. The temperature of the water should be kept constant during an analysis, as a variation in temperature causes convection currents to be set up in the suspension which hinder the true settling rate of the suspended particles.

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# Heat Treated Gray Iron Cylinder Liners

By W. Paul Eddy, Jr.,* Pontiac, Mich.

**Abstract**

*In an attempt to increase the life of automotive engine cylinders, considerable experimental work with various irons led to the adoption of cylinder liners of a 2.00 per cent nickel, 0.65 per cent chromium, cylinder iron. These liners are hardened by oil quenching from 1550 deg. Fahr. (843 deg. Cent.), and are tempered at 350 deg. Fahr. (177 deg. Cent.) for 2 hours. They have a hardness of approximately Rockwell C50 or Vickers Brinell 530, and a tensile strength of approximately 38,000 pounds per square inch (within 10 per cent of the as cast strength). Microstructure after heat treatment consists of a matrix of martensite with scattered cementite particles, and typical flake graphite.*

*A description of machining, heat treating, and assembling operations, as used for the manufacture of production quantities of cylinder liners, is given.*

*An average increase in cylinder life, in heavy-duty vehicle engines, of about 200 per cent has been effected by the adoption of these hardened liners to replace one-piece cylinder blocks of alloy iron having hardness of Brinell 235, with the additional advantage that the liners are renewable when worn out.*

## Introduction

1. The resistance to wear of cylinder bores of heavy-duty truck and coach engines has always been an important factor in the life and economy of operation of such vehicles. Hardness and strength of cylinder irons had been continually increased, until,

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Note: This paper was presented at one of the sessions on Cast Iron at the 1934 Convention of the A. F. A.

about three years ago, the cylinder block castings used by the company with which the writer is associated were of an electric furnace chromium-molybdenum iron having hardness of Brinell 229-241, tensile strength of not less than 45,000 pounds per square inch, and transverse strength (as measured on A.S.T.M. test bars on 18-inch centers) of not less than 3300 pounds.

2. Although this material represented approximately the hardest and strongest machinable iron available in such intricate castings as cylinder blocks, it was desired to effect still further improvement in cylinder life. The resulting investigations led to the adoption, in 1931, of hardened gray iron cylinder liners of the dry type. Since the original adoption of this type of construction, further improvements in both material and design have naturally been made.

3. This paper discusses briefly the development, manufacture, properties and service performance of these cylinder liners.

## DEVELOPMENT

4. The amount of experimental work involved has been large. Initially, experiments were conducted with ten different gray iron compositions, including nickel, nickel-chromium, manganese-nickel-chromium, and nickel-molybdenum, with varying amounts of alloying elements and total carbon, and with combined carbon contents from 0.50 per cent to 1.80 per cent as cast. This work involved hundreds of heat treating tests, together with analyses, strength tests, microscopic examinations and hardness tests. A large amount of experimental work in the machine shop was also found necessary in order to develop sound production methods and to minimize losses. Time and space limitations permit giving at this time but a brief summary of results obtained.

### *Some Requirements.*

5. The primary requirement was, of course, high hardness. It was also decided, because of the inherent fragility of large thin-walled cast iron cylinder liners as compared with many other automotive parts, and because liners must be handled and installed by garages as well as by our own factory, that little if any sacrifice in strength from that of the original castings could be tolerated. Soundness of castings was essential. Machinability

was important from the standpoint of cost. Freedom from distortion during heat treatment and ability to duplicate results consistently were also factors.

6. It was found that highest hardness after quenching was obtainable with a mottled iron which had previously been annealed to a commercially machinable hardness. The finely divided temper-carbon formed in annealing aparently redissolved readily upon heating for hardening, forming a high-carbon austenite which quenched to a very hard martensite. However, these types of iron had several disadvantages. First, the greater shrinkage of the low-graphite irons increased the difficulty of producing sound castings. Second, the annealing operation was difficult to control so as to obtain uniformly good machinability and consistent dimensional changes during subsequent hardening. Third, the small amount of graphite present appeared to be undesirable in a cylinder.

7. Low combined-carbon irons did not harden sufficiently. The best irons from every standpoint were those with slightly under one per cent combined carbon; such irons could be made into sound castings, machined readily as cast, and hardened uniformly with no appreciable change in free carbon contents.

8. In order to obtain iron of this type which could be cast in thin sections without chilling at edges, which would harden sufficiently by oil quenching and which would as nearly as possible fulfill the other requirements previously mentioned, the addition of approximately 0.65 per cent chromium, with sufficient nickel to balance, was found necessary. Such an alloy iron, which is used today, is not claimed to be the last word in hardenable cylinder liner irons, and experiments are still being conducted in an attempt to effect further improvement or to equal present performance at lower cost.

## SPECIFICATIONS

9. The complete specification for our cylinder liner iron, as in force at present, follows:

> *Quality:* Castings shall be smooth, well cleaned, and free from shrinkage cavities, cracks, sand holes, large inclusions, chills, excess free carbides, and any other defects detrimental to machinability, appearance or performance. They shall finish to the size specified.

*Composition:*

| | |
|---|---|
| Total Carbon | 3.10-3.40 per cent |
| Combined Carbon | .75- .90 per cent |
| Manganese | .55- .75 per cent |
| Phosphorus | Max. .20 per cent |
| Sulphur | Max. .10 per cent |
| Silicon | 1.90-2.10 per cent |
| Chromium | .55- .75 per cent |
| Nickel | 1.80-2.20 per cent |

*Physical Properties:*

Hardness, as cast—Brinell 212-241.

Transverse Strength (A.S.T.M. arbitration bars)—2400 pounds minimum.

Transverse Deflection—0.20-0.30 in.

Tensile Strength (test bars machined from castings)—37,000 pounds per square inch minimum.

*Soundness:* Cylinder liner castings, when machined to approximately ⅛ in. wall thickness, shall withstand 1500 pounds per square inch hydrostatic pressure, internally applied, without leakage or failure.

*Heat Treatment:* Cylinder liner castings with a wall thickness not greater than ⅜ in. shall, after being heated in an oven-type furnace at 1540-1560 deg. Fahr. for 30 to 40 minutes and quenched in still oil, have a hardness of not less than Brinell 512 or Rockwell C52.

## ADVANTAGES

9. Adoption of cylinder liners has permitted us to use a softer and cheaper iron for the blocks, the saving in material and machining thereof partially balancing the increased cost of the liners.

## PROPERTIES

10. Castings actually obtained to the above specification have properties, in general, in excess of the specified minima.

*Strength.*

11. Arbitration bars show transverse strengths of 2700 to 2900 pounds, on 18-inch centers.

12. Tensile strengths, in pounds per square inch, as determined from test bars machined from castings, are in the following ranges:

| | Lbs. per square inch |
|---|---|
| As Cast | 37,000-41,000 |
| Aged | 38,000-43,000 |
| Hardened | 28,000-36,000 |
| Hardened, and tempered at 300 deg. Fahr. (149 deg. Cent.) 2 hours | 33,000-39,000 |
| Hardened, and tempered at 350 deg. Fahr. (177 deg. Cent.) 2 hours | 36,000-40,000 |
| Hardened, and tempered at 450 deg. Fahr. (232 deg. Cent.) 1 hour | 39,000-43,000 |
| Hardened, and tempered at 600 deg. Fahr. (316 deg. Cent.) 1 hour | 45,000-56,000 |

13. Strength measurements have also been made by crushing machined liners radially between two flat parallel plates. Each load is measured at occurrence of the first crack, which is clearly audible. This test is more sensitive and gives more nearly reproducible results than does the tensile test. Average results of many crushing tests are as follows:

| | |
|---|---|
| Aged | 3850 lb. |
| Hardened | 2400 lb. |
| Hardened, and tempered at 300 deg. Fahr. (149 deg. Cent.) 2 hours | 3000 lb. |
| Hardened, and tempered at 350 deg. Fahr. (177 deg. Cent.) 2 hours | 3450 lb. |
| Hardened, and tempered at 450 deg. Fahr. (232 deg. Cent.) 1 hour | 3800 lb. |
| Hardened, and tempered at 600 deg. Fahr. (316 deg. Cent.) 1 hour | 3950 lb. |

14. Hardening may reduce strength anywhere from 10 to 40 per cent, the original strength being gradually restored by progressively higher tempering. It is well known that tempering at temperatures above 600 deg. Fahr. (316 deg. Cent.) produces strengths higher than that as cast, but hardnesses obtained thereby are much lower than we desire in cylinder liners. The best combination of hardness and strength seemed to be obtained by tem-

pering at 350 deg. Fahr. (177 deg. Cent.) for 2 hours; strength is approximately 90 per cent of that as cast.

*Hardness.*

15. Results obtained over a long period in heat treating cast iron are, in general, somewhat less uniform than those usually obtained in heat treating alloy steels. Most of these cylinder liners harden satisfactorily when oil quenched from 1475 to 1500 deg. Fahr. (802 to 816 deg. Cent.), but there are some which require heating to slightly higher temperatures in order to produce maximum hardness after quenching. Variable hardening temperatures are undesirable from the standpoint of uniform distortion and growth, so that we have standardized on heating in an oven furnace at 1550 deg. Fahr. (843 deg. Cent.) for a total time of 32 minutes.

**Table 1**

| Treatment | Hardness | | |
|---|---|---|---|
| | Brinell | Vickers Brinell | Rockwell |
| As cast and after aging | 217-248 | ..... | B 96-101 |
| Hardened | ..... | 570-650 | C 52-57 |
| Hardened, and tempered at 300 deg. Fahr. (149 deg. Cent.), 2 hr. | ..... | 530-610 | C 50-55 |
| Hardened, and tempered at 350 deg. Fahr. (177 deg. Cent.), 2 hr. | ..... | 500-580 | C 48-53 |
| Hardened, and tempered at 450 deg. Fahr. (232 deg. Cent.), 1 hr. | ..... | 470-530 | C 46-50 |
| Hardened, and tempered at 600 deg. Fahr. (316 deg. Cent.), 1 hr. | ..... | 450-500 | C 44-48 |

16. Hardnesses of liners are quite consistently within the ranges shown in Table 1.

*Microstructure.*

17. Typical microstructures are shown in Figs. 1 and 2. It will be noted that the matrix of the liner before hardening consists of about equal quantities of sorbite and finely lamellar pearlite, with an appreciable quantity of free cementite in fairly well distributed particles; with combined carbon approaching the upper specified limit, the carbide particles tend to form a coarse broken network. The hardened liner structure is finely martensitic, apparently darker and finer near each carbide particle where some cementite has been dissolved and partly diffused during heating and reprecipitated in the form of tiny spheroids on

quenching. No difference between the structures as hardened and after tempering at 350 deg. Fahr. (177 deg. Cent.) is apparent.

*Distortion in Hardening.*

18. Hardness obtained by water-quenching these liners is the same as that after oil-quenching. Following are results of a number of tests on machined liners, 4-13/16 inch inside diameter and 5-1/8 inch outside diameter, heated in an upright position on the hearth of an oven furnace at 1550 deg. Fahr. (843 deg. Cent.)

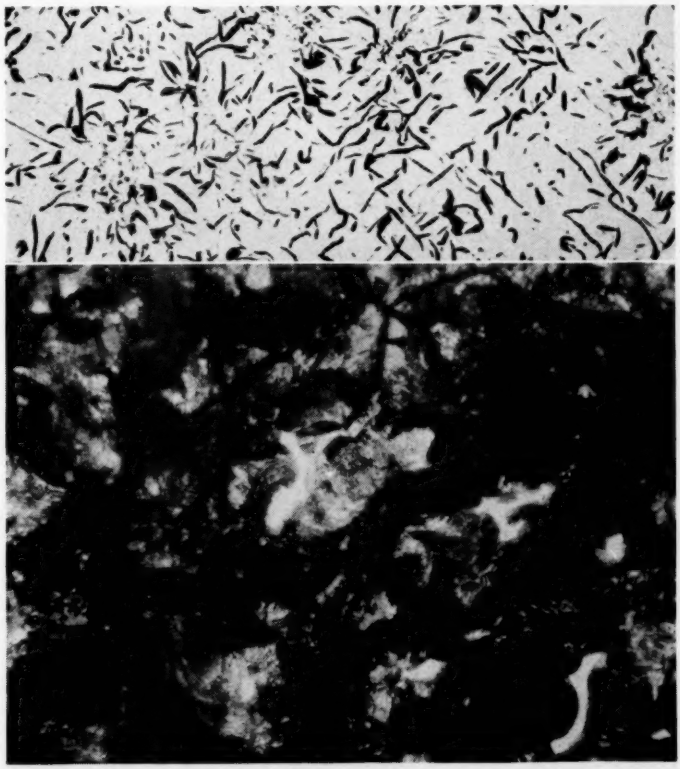

FIG. 1—STRUCTURE OF CYLINDER LINER. COMPOSITION: TOTAL CARBON, 3.33 PER CENT; COMBINED CARBON, 0.78; MANGANESE, 0.71; PHOSPHORUS, 0.148; SULPHUR, 0.058; SILICON, 2.03; CHROMIUM, 0.67; NICKEL, 2.18. CONDITION: AGED 2 HOURS AT 1035 DEG. FAHR. (557 DEG. CENT.). (A) MAGNIFICATION 100X, UNETCHED. (B) MAGNIFICATION 500X, ETCHED 1 PER CENT NITAL, 2 MINUTES.

for 35 minutes, and quenched in an open tank with a slow up-and-down motion:

| | Water Quench | Oil Quench |
|---|---|---|
| Increase in average diameter | .013-.018 inch | .010-.014 inch |
| Out-of-roundness | .012-.020 inch | .002-.006 inch |

*Size Change in Service.*

19. Another characteristic, which would be evident in any thin-walled cylinder liner, is worthy of note. In our original design, liners were finish-ground on outside diameters to .003-.005 inch larger than the ground bore diameters in the blocks. Liners were assembled into blocks from the bottom, the tops of liners be-

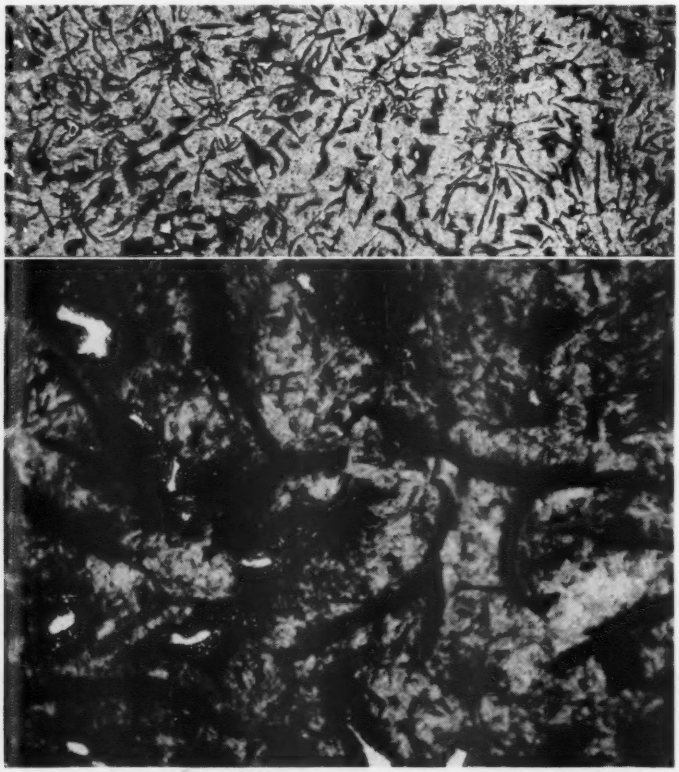

FIG. 2—STRUCTURE OF CYLINDER LINER. COMPOSITION: SAME AS IN FIG. 1. CONDITION: HARDENED BY HEATING TO 1550 DEG. FAHR. (843 DEG. CENT.) AND OIL QUENCHING, AND TEMPERED AT 350 DEG. FAHR. (177 DEG. CENT.) FOR 2 HOURS. (A) MAGNIFICATION 100X, ETCHED 1 PER CENT NITAL, 3 MINUTES. (B) MAGNIFICATION 1000X, ETCHED 1 PER CENT NITAL, 4 MINUTES.

ing nearly flush with top surfaces of blocks. A maximum load of 6,000 to 12,000 pounds was required to press a liner into position.

20. Although this amount of press fit was ample, the press fit was found to decrease gradually during operation of the engine. As the liners naturally become hotter than the surrounding metal of the block, the radially compressive stresses on the liners increase until the elastic limit at the operating temperatures is exceeded, when the liners suffer slight permanent contraction. Although the diameters of liners in cylinder blocks are unchanged, their "free" diameters have been decreased, and the amounts of press fit have been proportionately lessened. This action may, in extreme cases, proceed so far that press fits, when cold, become low enough to permit liners to slip down slightly in the blocks. Our present design, which includes a small flange at the top of the

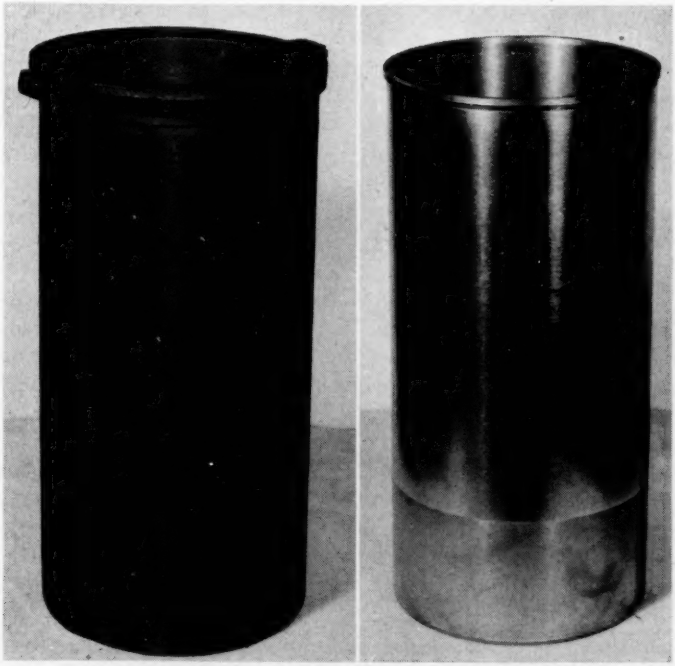

Fig. 3—(A) Cylinder Liner As Cast. Size: Approx. 10¾ in. Long x 5½ in. Outside Diameter x 4¾ in. Inside Diameter. (B) Cylinder Liner. Heat-Treated, Rough-Ground in Bore, Finsh-Ground Elsewhere; Ready for Assembling.

liner and a counterbore of equal size in the top of each bore in the cylinder block, and involves assembling liners into blocks from the top, eliminates the possibility of displacement of liners in operation.

## MANUFACTURE

21. Liner castings are made by Frank Foundries Corporation, who for many years furnished sleeve castings for sleeve-valve engines formerly made by our company. The mold is made in a special three-part flask, the liner being cast in a vertical position with the flanged end up (in the same position as that of the finished liner in the engine), and with a tangential gate at the bottom end, the body of the casting being free from parting line and gate. A special air-jolt, air-strip molding machine having 12 inch draw is used to make the center portion of the three-part mold. An unusually large feed-head is required. Cupola-melted cylinder iron is used, the necessary alloy additions being made in the ladle. A typical liner casting is shown in Fig. 3. The lugs on the upper end are for driving in the rough-machining operations; only one lug is used, but each casting is made with two lugs, as a lug is occasionally broken off during shipment or during machining.

22. Manufacturing operations are as follows; the accompanying illustrations show the few operations which are performed in perhaps unconventional ways; all machining prior to heat treatment is done without lubricant or coolant:

(1)—*Age*—Castings are placed, in upright position, on five flat cars, each approximately 3 x 4 ft. The cars are run on rails into an oil-fired oven-type furnace the hearth dimensions of which are 4 ft. x 15 ft. x 27 inches high. The furnace is heated to 1025-1040 deg. Fahr. (552-560 deg. Cent.) and held for 2 hours at temperature, following which the work is cooled in the furnace to 400-450 deg. Fahr. (204-232 deg. Cent.). Each car holds about 48 liner castings, giving a furnace load of 240 castings. No change in Brinell hardness or microstructure of the iron can be detected as a result of this treatment.

(2)—*Rough-bore*—Castings are located on outside surfaces in V-blocks, in a Holehog highspeed vertical four-spindle boring mill, four liners being bored simultaneously. Each boring bar holds two stellite tools. Depth of cut is approximately .065 inch, speed 55 feet per minute, feed .022 inch per revolution.

(3)—*Rough-turn Outside Diameter and Rough-face bottom*

*end*—Liner is placed on an expanding arbor on a P & J automatic lathe. A hollow tool-head holds three turning tools, 120 degrees apart, and one facing tool, all Stellite. The flange is not machined. Depth of cut is approximately .095 inch, speed 42 feet per minute, feed .087 inch per revolution.

(4)—*Face top end*—Liner is placed on an expanding arbor on a LeBlonde lathe with automatic feed. One Stellite facing tool is used, and the liner is faced to 1/8 inch over the finished length.

(5) *Chamfer bore*—Liner is placed on a snug-fitting pilot and turned by hand against a counterbore integral with the pilot. The operation is then repeated with liner reversed. This is one of the essential operations in producing round liners. (Figure 4)

(6)—*Finish-turn outside diameter*— Liner is held on bell centers, locating from bore chamfers, on a LeBlonde automatic feed lathe. A single Stellite tool is used. Depth of cut is .030 inch, speed 137 feet per minute, feed .054 inch per revolution.

Fig. 4—Chamfering Bore of Liner.

Outside diameter is .010 inch over finished size after this operation.

(7)—*Ream bore*—Liners are held in a four-pot chuck, on a Foote-Burt vertical four-spindle boring mill. High-speed steel inserted-blade reamers are used. Depth of cut is .018 inch, producing bore diameter .032 inch below finished size.

(8)—*Finish-face bottom end, turn flange outside diameter, face bottom of flange, turn undercut adjacent to flange, finish-chamfer bore*—Liner is held on an expanding arbor on a LeBlonde lathe. Two special tool blocks, holding a total of five high-speed steel tools, are fed by hand. In this operation, the lugs cast on the flange, by which the liner was driven in operations 2, 3, 6 and 7, are removed, the flange diameter being turned to 3/64 inch over finished size.

(9)—*Mill driving grooves*—Liner is held in a fixture on a hand milling machine, and two 1/4 inch wide x .020 inch deep grooves, approximately 180 degrees apart, are cut, by a 6 inch diameter high-speed steel saw, in the flange outside diameter. These grooves are used for driving during grinding operations.

(10)—*Hydrostatic Test*—Each liner is clamped in the test ma-

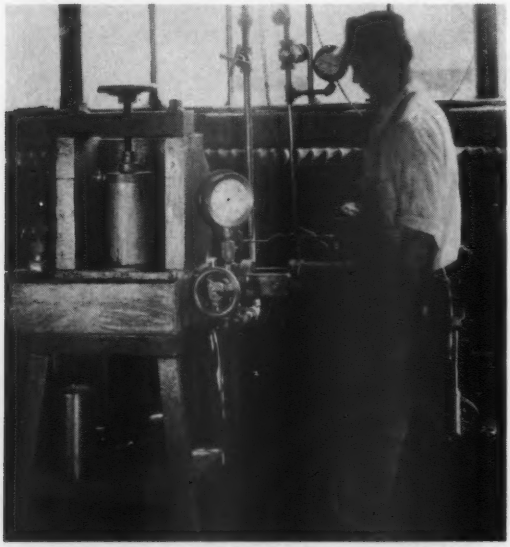

FIG. 5—HYDROSTATIC TEST OF LINER. (FRONT COVER-PLATE OF TEST FIXTURE REMOVED TO SHOW LINER IN POSITION.) ON LOWER SHELF OF STAND IS SHOWN A LINER WHICH HAD FAILED IN THIS TEST.

chine, which is of our own design and manufacture, the liner ends being sealed by gaskets. The liner is filled with water and a pressure of 1500 pounds per square inch applied by a compressor. This test detects tiny cracks and invisible porosity; a liner containing any such defect cracks longitudinally before the prescribed pressure is reached. The test is shown in Figure 5. Frequent tests of liners to destruction show that acceptable liners fail at pressures of from 2000 to 3500 lb. per sq. in.

(11)—*Harden*—Two oil-fired oven-type furnaces, each having a hearth 2-1/2 ft. wide x 3 ft. deep, with door opening 23 in. wide x 14-1/2 in. high, are used. In operation, a temperature of 1540-1560 deg. Fahr. (838-849 deg. Cent.) is maintained. The furnace is gradually loaded with eight liners, in two rows of four each extending from near the two front corners of the hearth to near the center of the back. Every four minutes, one of the two liners in the rear is removed and quenched, the remaining three liners in that row are slid back one position, and a cold liner inserted at the front of the row. Alternate rows are manipulated every four minutes, giving a total time in the furnace for each liner of 32 minutes. Care is exercised to prevent liners touching each other or the furnace walls. By this procedure, liners are removed for quenching from the hottest and most uniform part of the furnace, and each liner is, in its last position, immediately adjacent to the thermocouple. The furnace door is of course closed except during the few seconds out of each four minutes required to transfer the liners. Leeds & Northrup recording potentiometers give a continuous and permanent record of furnace temperature. Figure 6 illustrates the method of loading the furnace. The liner to be quenched is slipped over an arbor the outer surface of which consists of many fine teeth with top surfaces ground to approximately .014 inch over the reamed diameter of the liner, and the arbor holding the liner is lowered vertically into an oil tank and moved slowly up and down, while submerged, until the liner has become cold. As the liner diameter naturally increases approximately .012 inch during hardening, and as a thin scale is formed during heating, the liner is tight on the arbor after being quenched; the arbor, however, is built up of a number of sectors held in position by a tapered shaft through the center, so that a slight turn of a large hand nut on the top end frees the liner by slightly collapsing the sectors. The usual out-of-round distortion without the quenching arbor is less than .006 inch, but an appreciable

percentage of the liners hardened will distort a greater amount. Use of the quenching arbor not only increases size uniformity but insures against out-of-roundness of more than .005 inch even after tempering. The quenching oil is continuously circulated through coils surrounded by cold water and back to the quenching tank;

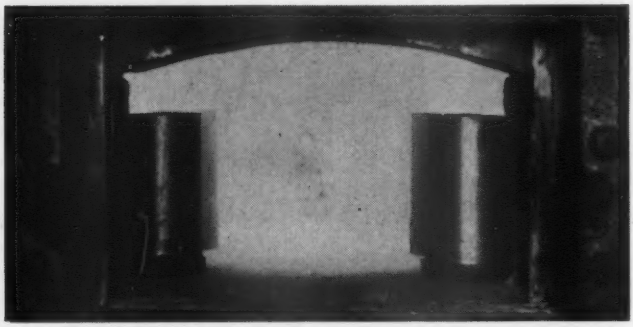

FIG. 6—HEATING LINERS FOR HARDENING. LINERS IN THIS PHOTOGRAPH ARE OF THE DESIGN FORMERLY USED, ASSEMBLED INTO BLOCKS FROM THE BOTTOM.

oil temperature is maintained at 90-100 deg. Fahr. (32-38 deg. Cent.). Our specification for the quenching oil follows:

> Oil shall be a straight-run, properly refined petroleum product, free from water, sediment, acid, resin or any substance not derived from petroleum. It shall not corrode any metal used for machine construction. Physical properties shall be within the following limits:
>
> Saybolt Universal Viscosity
> 100 deg. Fahr.....80-100 seconds
> Flash Point.....335 deg. Fahr. Min.
> Fire Point.....385 deg. Fahr. Min.
> Pour Point.....Max. 35 deg. Fahr.
> Color, NPA.....Max. No. 3
> Neutralization No.....Max. 0.05

(12)—*Wash*—Liners are placed in a wire basket and immersed in a boiling solution of a phosphate-carbonate-hydroxide cleaner, and are then rinsed in clean hot water. This operation removes the oil and much of the scale, which is mostly loose and non-adherent.

(13)—*Temper*—A continuous, gas-fired, hand operated pusher type furnace, having hearth 6-1/2 ft. x 1-1/2 ft. x 1 ft. high, is

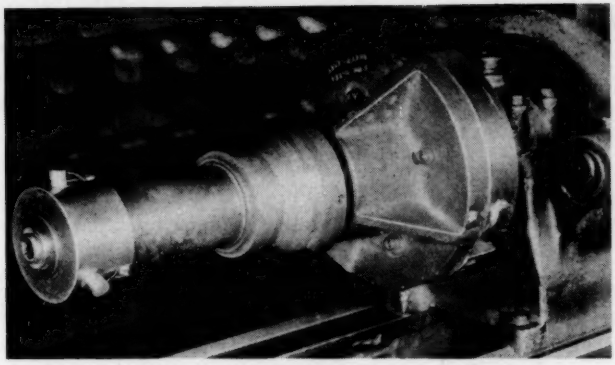

Fig. 7—Bore Chamfer Grinding Arbor. A Plug-Wrench Has Been So Designed That an Operator Cannot Exert Sufficient Pressure on the Three Expanding Points to Distort the Liner.

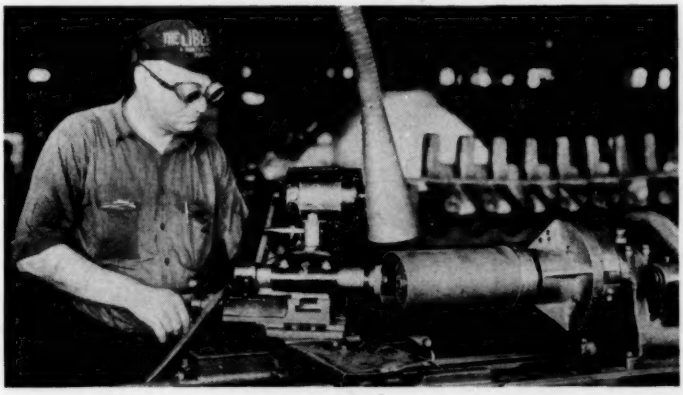

Fig. 8—Grinding Bore Chamfer.

used. Six liners are placed, in vertical position, on an 18 inch x 15 inch tray. The furnace holds four trays, and a push is made every 30 minutes, the trays entering at one end and discharging at the opposite end, each tray being in the furnace 2 hours. Temperature is controlled at 350-370 deg. Fahr. (177-188 deg. Cent.).

(14)—*Grind centers*—The liner is mounted on a special expanding arbor, having a bell center on one end and a three-point centering device on the other, on an engine lathe. The bore-chamfer on the open end is ground with a Dumore grinder

mounted on the tool carriage, and the liner is then reversed and the operation repeated on the opposite end. The wheel is a 3-1/2 inch x 1/2 inch Norton 1846K. This operation is the key to the production of perfectly round liners. Figure 7 shows the arbor and Figure 8 the operation.

(15)—*Finish-turn undercut adjacent to flange*—Liner is held on bell centers, locating from the ground bore chamfers, and undercut is turned to .002 inch below finished liner outside diameter, using a cemented tungsten carbide tool.

(16)—*Finish-grind outside diameter*—Liner is held on bell centers, and is driven from one of the slots milled in the flange by a flexible driving ring (which does not distort the liner) clamped to the flange. The machine is a Norton cylindrical grinder and the wheel an 18 in. x 2 in. x 5 in. Bay State 7246-L5-AA. Grinding is wet. Three roughing passes, each cut removing about .0035 inch on a side, and two finishing passes, each removing .00075 inch on a side, are made. The speed is 6200 feet per minute.

(17)—*Rough-grind bore*—Liner is mounted in a pot chuck, locating from the ground outside diameter and driving from a flange slot by an adjustable dog, on a Bryant grinder. The wheel is a 4-1/2 in. x 1 in. x 1-1/4 in. Carborundum 40S. Grinding is dry. Approximately nine passes, each removing .001 inch on a side, are required. The speed is 5800 feet per minute. The bore after this operation is .007-.009 inch below finished size.

(18)—*Grind relief on lower end, grind flange diameter, face-grind top end*—Liner is mounted on an expanding arbor on a Norton grinder. The same type of wheel as that of Operation 16 is used, and grinding is wet. This operation (18) is controlled by hand feed. The grinding of the flange diameter removes the driving slots. Figure 3B shows a liner after this operation, the liner being finished, as far as the liner department is concerned, and ready for assembling. It may be noted that, exclusive of heat treatment, all the foregoing operations, as a result of careful grouping, timing and apportioning of the proper number of machines for each operation, are performed by six men, who completely process 16 liners per hour or 112 per seven-hour shift; the total labor for machining and grinding a liner is 22-1/2 minutes.

(19)—*Assemble liners and cylinder block*—Although cylinder

blocks are bored and liners are ground to .002 inch total tolerance, each bore and each liner is measured and classified high-limit, mean, or low-limit. Selective assembly is used, a high-limit liner going into a high-limit barrel, and so on. This practice gives a press fit of close to .0025 inch. This is purely a control measure, as it has been proven that satisfactory performance is obtained with any assembly within the machining tolerance. (High-limit liners only are used for Service, thus insuring good thermal contact between the liners and any cylinder block in the field.) The cylinder block is immersed in boiling water for 15 minutes, then quickly mounted in guides on the table of a friction-drive vertical spindle power press having hydraulic connection to the plunger. A pressure gauge connected to the hydraulic chamber is calibrated to read total pressure in pounds on the plunger. Liners at room temperature are pushed, one by one, into the bores, with no lubricant. The gauge must read between 3000 and 4500 pounds when each liner is one inch above its assembled position. Each barrel is counterbored .005 inch deeper than the depth of the liner flange. In its final position, the top surface of the liner is .002 inch above the top surface of the block; this is controlled by the piloted compression plate, which is counterbored .002 inch deep to fit on the liner; contact of the plate against the cylinder block terminates the assembling operation.

(20)—*Assemble cylinder block studs and plugs*—This operation is conventional, except that the use of stainless steel Welch plugs is worthy of note.

(21)—*Water test*—All water-passage holes are closed by special gaskets, the water passages in the block are filled with water under a pressure of 90 lb. per sq. in., and the entire block is examined for leaks. The slightest leak means a scrapped block, as no salvaging is permitted.

(22)—*Finish-grind cylinder bores*—A horizontal spindle Heald (Model 50) cylinder grinder, having ball-bearing spindle, is used. The wheel is a 4 in. x 1-1/4 in. x 1-1/4 in. Bay State 462H. Speed is 6500 feet per minute. The total amount of stock to be removed is .009-.012 in. on the diameter; three roughing passes, each removing .0015 in. on a side, and two finishing passes, each removing not more than .0005 in. on a side, are usually required. Grinding is dry, but during the operation water is pumped through the water passages of the block and is made to flow over the liner skirts which project below the bottom of the block.

## SERVICE PERFORMANCE

23. Cylinder liners are used in the four largest engines we build—Types 468, 525, 616 and 707; the type numbers being the respective displacements in cubic inches. All are six-cylinder, valve-in-head engines, having heat treated aluminum alloy pistons and cast iron piston rings of Rockwell B100-106 hardness. These engines are used in large coaches and trucks, the majority in the former. New engines are run under load on dynamometers for 12 to 16 hours before assembling into vehicles. With the one-piece cylinder blocks formerly used, having hardness of Brinell 229-241, the present blocks with hardened liners may be contrasted on several points.

24. With the old blocks, running equivalent to 400-600 miles was required to break-in the rings and cylinder walls; the breaking-in was therefore complete at the end of the dynamometer run. The new engines require 3500-5000 miles to completely break-in the rings, as the cylinder walls do not wear appreciably, although the engines can be operated on regular schedule as soon as purchased, without harmful effects. The longer break-in period means that oil consumption is usually high at first, gradually dropping off to a satisfactorily low figure as breaking-in is completed. Average consumption of the largest engine (the 707) is 50-60 miles per quart at first, and 200-250 miles per quart after breaking in. Thereafter, consumption remains constant for a considerable period, then gradually increases as the engine parts wear; both old and new type cylinders are usually reconditioned by operators when mileage of less than 50 per quart is attained.

25. The old blocks were usually reworked by honing to .010 in. oversize and installing .010 in. oversize pistons and rings. Blocks could be reconditioned in this manner until .030 in. oversize (although some operators rehoned a fourth time to .040 in. oversize), after which blocks were scrapped.

26. Blocks with liners are usually reworked by grinding (they can be honed but this is rather tedious) to .010 in. oversize and installing oversize pistons and rings. Liners can be reground as many times as could the old cylinder blocks, after which the blocks are not scrapped but are refitted with new liners.

27. Life of a cylinder block between reconditionings varies considerably, depending on operating conditions and maintenance practices. Type of operation (city or cross-country), type of roads, speeds, lubrication policies, kind of fuel, corrosive condi

tions in combustion chambers, and maintenance of efficiencies of air cleaners, oil filters, oil coolers and engine cooling systems are some of the factors that influence engine life.

28. In spite of these variables, our records provide fairly definite data. The old-style cylinder, under such varying conditions, ran 25,000 to 75,000 miles between reconditionings. The new cylinders, although operating in general on faster schedules, run 75,000 to 200,000 miles between reconditionings; furthermore, in many operations which are more severe, it is merely necessary, after 75,000 to 125,000 miles, to install new standard size piston rings, the engine then being run 50,000 to 75,000 miles further before cylinder grinding and oversize pistons and rings are required.

29. Tests on many liners after long service have shown that no measurable drop in hardness occurs during operation.

30. The operating costs of our engines have obviously been materially reduced by the use of hardened inserted cylinder liners. This is more readily appreciated when it is remembered that a total mileage of a coach in excess of 500,000 is not at all uncommon. The new engine not only requires but one-third as many cylinder reconditionings than the old, but also uses the same cylinder block throughout its life.

## ACKNOWLEDGMENTS

31. The author wishes to express his appreciation to the management and engineering executives of General Motors Truck Corporation for their support and encouragement, and to acknowledge gratefully the assistance of several persons in the preparation of certain portions of the paper, especially Mr. A. W. Zimmer (manufacturing methods), Mr. L. T. Flynn (service performance), and Mr. W. H. Sanderson (illustrations and photomicrographs).

## DISCUSSION

R. L. ADAMS[1]: (*Submitted in Written Form*) The author is to be congratulated on the thoroughness and brevity with which he has covered his subject. The methods and fixtures used, particularly the quenching arbor, are of interest from both metallurgical and production standpoints. It is evident that the selection of the best possible composition of iron for these liners must have involved a far greater amount of work than that mentioned by the author.

[1] National Superior Co., Toledo, O.

It would be interesting and desirable if Mr. Eddy would give more details of the original mixture; that is, whether or not it is preferable to use raw materials which contain little or no primary graphite. The physical properties given in Mr. Eddy's paper are in general agreement with those shown by F. B. Coyle in his article in "Metals and Alloys" of September, 1931.

MR. EDDY: As stated, the amount of experimental work involved was large. I did not consider it necessary to give all the results of the many tests, some of which, especially in the early stages of the work, it must be admitted, seemed not quite as consistent as could be desired. However, we finally were able to obtain fairly consistent figures with large numbers of liners.

As implied in the paper, the irons containing low primary graphite are desirable from the standpoint of high obtainable hardness after quenching. It is necessary to subject such irons to long high-temperature annealing treatments before machining. The chief difficulty with sand castings, and in some cases with centrifugal castings, was producing sound liners with this type of iron. I have seen some sand castings, however, which were fairly sound, and further work with these irons might result in consistently good results.

One iron which gave excellent results as far as hardness is concerned had the following composition, as cast: Total carbon, 3.06 per cent; combined carbon, 1.80 per cent; manganese, 0.77 per cent; silicon, 1.75 per cent; chromium, 0.97 per cent, and nickel, 1.94 per cent.

The hardness of this iron, after quenching, was appreciably higher than that obtained with the mix that we are now using, but, due to the disadvantages previously mentioned, this type of iron has not been used in production.

G. P. PHILLIPS[2]: (*Submitted in Written Form*) Mr. Eddy is to be congratulated upon the concise, thorough paper that he has presented.

The use of an iron containing about 3.35 per cent total carbon and about 2.50 per cent graphite is of interest particularly in regard to the influence of the graphite content on service life. The inference is made that materially lower graphite content might result in lower wear resistance which seems correct to the writer in view of our experience on other types of automotive castings.

The presence of about 0.65 per cent chromium in the metal aids in preventing growth during heating for hardening and assists in obtaining fairly fine discontinuous graphite particles in the "as cast" condition. This is important as the overall hardness of the hardened casting is fundamentally an average of the hardness of the metal and the graphite particles contained in it.

The nickel content of about 2.00 per cent, in addition to aiding machinability, and preventing chill at edges, lowers the critical temperature and helps in obtaining consistent results.

There remain many problems yet to be completely worked out and many points to be evaluated. One of these is the optimum total carbon and graphite contents for best service results. It is possible that a still

[2] Frank Foundries Corp., Moline, Ill.

higher total carbon and higher graphite iron may have still better wear resistance even with somewhat larger graphite particles of greater quantity. Such an iron might show somewhat lower hardness values due primarily to more graphite and yet have a matrix of equal hardness as that of the metal described by Mr. Eddy.

There is also a question among some users of hardened cylinder liners, as to the best type of piston rings to be used in conjunction with them, particularly with respect to the relative hardness of the rings and liners. This question is obviously of considerable importance to operators of trucks and coaches as regards economy of operation.

MR. EDDY: We have always considered a considerable amount of graphite necessary to successful operation, in a cylinder. We have not, however, done an appreciable amount of work with low graphite iron as far as service performance is concerned, and I am not prepared to say that less graphite means lower wear resistance. The possibility of using still higher graphite contents is interesting, but I believe that the chief function of the graphite is to retain lubricant, and, provided sufficient graphite be present to fulfill this function, additional amounts are unnecessary. I do not presume to say that I know just what the optimum amount of graphite is for cylinders in our engines and it is possible, as Mr. Phillips suggests, that further work along these lines might yield interesting results. Some aviation engines, by the way, operate satisfactorily with steel cylinders.

It is possible that somewhat harder piston rings must be used with hard liners to advantage, but, with our present set-up, in the majority of cases, rings do not require replacement before liners need regrinding. Therefore, we have hesitated to put harder rings in production, knowing that the mileage prior to complete break-in, with its consequently high oil consumption, would thereby be extended.

MEMBER: If I understood Mr. Eddy correctly, the 75,000 to 200,000 miles between reconditionings obtained with the heat-treated liners was compared with 25,000 to 75,000 miles on the blocks without liners.

MR. EDDY: That is correct.

MEMBER: Have you any figures that would show the relative wear of un-heat-treated liners as compared with the heat-treated liners?

MR. EDDY: No, I haven't.

MEMBER: You went from the cylinder block without liners directly to the heat treated liners?

MR. EDDY: That is correct.

MEMBER: Has the author taken hardness tests from liners removed from engines. There seems to be some influence on hardness from comparatively low temperatures, and I wonder if the operation of the engine over a long period has any influence on the hardness of the liners.

MR. EDDY: Brief mention of this point was made in the paper. We were concerned, at first, about this possibility, so that, from a number of engines returned from time to time after long mileages for reconditioning. the liners have been removed and tested for hardness. I cannot say that there is no change, but I have yet to find a liner the hardness of which,

after considerable service, is below our specified minimum; so that the change, if any, is very slight.

MEMBER: This is a very interesting development, and it has been very beautifully presented to us. I wondered if, in his experimenting with various irons before he finally settled on the one described, Mr. Eddy had done anything with nitrided cylinder liners, and, if so, if he is willing to tell us something about his experience therewith.

MR. EDDY: We did no work with nitrided cast irons before adopting our present liner, as we knew nothing about them at that time. Since the present liners were adopted, however, we have done a little work with nitrided irons, but I cannot tell you much about them as yet. The first lot of nitrided liners went into service, in large coach engines, in December, 1932—nearly two years ago. Three cylinders of each (six-cylinder) engine contained our present 500 Brinell liners, and the other three the nitrided liners. Thus far, regrinding has not been necessary on any of the liners. At the next opportunity, however, these engines will be taken down and, even though regrinding of bores is still unnecessary, measurements of liner diameters will be made in an attempt to determine whether or not any difference in the amount of wear between the two types of liners exists. We have other nitrided cast iron liners which have gone into service during the past year, but we have nothing to report on those as yet.

To be used in production, nitrided liners would have to run much farther than do our present liners without reconditioning, because of the greater difficulty of grinding and the soft surface which would be produced by grinding off the nitrided case. In fact, it is possible that liner life equal to the life of the engine might be required because of these reasons and because of the much higher initial cost of nitrided liners. Nevertheless, it is conceivable that even this condition may be fulfilled, because of the greater corrosion-resisting properties as well as the higher hardness of nitrided iron. The use of very hard (nitrided) liners might also involve again the question of suitably hard piston rings.

HARRY RAYNER[3]: I realize that the proper place to take tensile strength specimens is from the actual casting; but, in order to compare this liner iron with regular cylinder iron, are there any figures showing tensile strengths of arbitration bars cast from this liner iron?

MR. EDDY: Tensile strengths of test bars machined from arbitration bars are approximately the same as those of bars machined from liner castings before heat treatment. The former are slightly higher, but the difference is small.

MR. RAYNER: Do you attribute the benefits derived from the liner to the original mix used or more to the heat treatment? In other words, could you take cylinder iron, for instance, and heat-treat it and obtain proper liners? The reason I ask this question is that bars taken from our cylinder iron run from 38,000 to 42,000 pounds per square inch in tensile strength, although cylinder walls are not to be compared with these liners on account of being in the center of the large block casting.

[3] Chrysler Corp., Detroit.

Do you place special emphasis on the original mixture to obtain liner iron, or do you use the regular cylinder iron mix and heat treat?

MR. EDDY: Our liner iron is really a cylinder iron, containing but slightly larger amounts of alloying elements than we use for heavy-duty cylinder blocks with integral bores, though with considerably more alloy than ordinarily used in passenger-car cylinders. It is probable that any good cylinder iron, if cast into liners, would approximate, in as-cast physical properties of the liners themselves, the figures I gave for our liners.

We are rather fussy about our specifications for liner castings; it may be noted that this specification is the only one of the several pearlitic iron specifications used in General Motors in which a certain composition is mandatory. This maintaining of definite composition limits is, of course, in the interest of uniformity in heat treatment. However, I know that hardness not far below that which we obtain can be produced by heat-treating gray cylinder irons containing much lower percentages of alloying elements, and that strengths of liners of such irons will also be satisfactorily high.

To answer Mr. Rayner's questions more directly—we believe the primary reason for the increase in service life obtained through the use of these liners is the high hardness. The mix used gives uniformly good results, month after month, but I do not attempt to say that we have the last word in liner iron composition. It is entirely possible that any one of several cylinder iron mixes, suitably controlled, could be machined and heat-treated with equally good results.

As far as service performance is concerned, please understand that our initial development work was done principally in the laboratory and the heat-treating department. Once we had an iron which we considered dependable, and had worked out the best heat-treating procedure for that iron, we put liners into production for one engine. As soon as it was found that this change had increased cylinder life, similar revision of the other three heavy-duty engines was made. Although the liner iron has been slightly modified since production was started, the type of iron has remained the same, so that all our performance data which amounts to anything is based on this one type of iron, as compared with the one-piece cylinder blocks having Brinell 229-241 hardness.

# Deoxidation and Degasification of Nonferrous Casting Alloys: General Principles—

## An Introduction to Symposium

By C. H. Lorig,* Columbus, O.

1. In this second annual symposium on deoxidation and degasification of nonferrous casting alloys, the influences in metals and alloys of elements that exist as gases in their normal free state will be repeatedly brought to the foreground. Such elements are in almost every industrial metal and alloy, but unfortunately, it appears, less is known about their effect and distribution than is known about the more obvious metallic forms of impurities. As the problems relating to deoxidation and degasification are both complex and confusing, a review of some general principles underlying the existence and control of non-metallic elements in metals seems warranted.

2. Before proceeding with the subject, a word may be said on nomenclature. In adopting the term "non-metallic elements" as descriptive of the substances usually involved in the word "gases," the proposal of a committee recently appointed by the Iron Steel Division of the A.I.M.E.[1] to study the nomenclature relative to the general subject of gases in metals is given recognition. The term non-metallic elements is less confining and more explicit than the word gases, and it removes some of the needless confusion introduced by the latter. It is, of course, as applicable to nonferrous as it is to ferrous metals and alloys, including as it does such elements in oxygen, nitrogen, hydrogen, carbon, and sulphur.

3. The sources for non-metallic elements in metals are numerous. They may enter the metals with the raw materials, fuel, and fluxes, or they may come from the products of combustion, from the furnace atmosphere, from reactions between the metals and the furnace gases, from moisture in the crucible and refractories, from entrapped gases in the mold, from reactions between

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[1] Yensen, T. D., and Herty, C. H.: *Terminology Relating to Non-Metallic Elements in Metals*, T. P. 555. Metals Technology, June 1934, Published by A.I.M.E.

Note: This paper is one of the papers presented in the above mentioned symposium held at the 1934 Convention of the A. F. A.

the metals and the mold materials, and from gas generated in the mold or core. For the most part, however, the presence of dissolved non-metallic elements in the melt may be ascribed to two major sources: first, from direct contamination of the melt by furnace fuels and products of combustion, and second from the metals used to make up the alloys.

## Moisture Causes Difficulties

4. In each of the foregoing it is moisture to which most of the difficulties ascribed to non-metallic elements can be traced. It reacts with a large number of molten metals to form an oxide, that is either dissolved, suspended, or slagged off, and hydrogen, part or all of which may be absorbed by the metals. Some hydrogen may be absorbed by metals through contact with ammonia and hydrocarbons, yet the chief source for hydrogen pick-up is from the reaction of the metals with moisture. Since hydrogen is recognized as one of the principal elements in promoting unsoundness in some castings, its importance must not be overlooked.

5. The introduction of oxygen from moisture into metals has been referred to. Other sources for oxygen are corroded or moist metal in the melting charge, oxygen in the atmosphere, and carbon monoxide and dioxide, the latter either dissolving in the metal or reacting to form metallic oxides.

6. While other non-metallic elements sometimes give rise to unsoundness in castings, the major causes for this condition are likely to be traced to the elements hydrogen and oxygen. In consequence of this, their roles are particularly emphasized in this discussion on principles.

7. Certain non-metallic elements are simply dissolved both in the liquid and in the solid metals, and others are in suspension either as gases or vapors in blowholes and shrinkage spaces, or as liquid or solid inclusions. Whether in solution or existing as liquid or solid inclusions, hydrogen, oxygen, and other elements lose their identity as gaseous elements and form structures with metals that are analogous to those formed by some elements solid under ordinary atmospheric conditions. Thus, hydrogen may occur in metals as atomic hydrogen and as hydrides in solution or in suspension; likewise oxygen may occur as atomic oxygen or oxides, and nitrogen as atomic nitrogen or nitrides. Their solubility expressed in weight percentages in liquid and solid metals is small, with the solubility in the liquid generally the greater.

8. Hydrogen will dissolve with ease in many molten metals. The reason, perhaps, is because it is a small atom and hence possesses more penetrative and diffusive ability than most other non-metallic elements. Because of this and of its abrupt discontinuity in solubility at solidification temperatures, hydrogen has been recognized as one of the principal elements in promoting unsoundness in castings.

9. There are cases where hydrogen appears to form true alloy systems with metals, as with palladium, cobalt, and nickel.

10. Whereas hydrogen, for the most part, simply dissolves in the metals, oxygen combines with most of them to form oxides. Though the oxides most frequently occur as slag inclusions of various kinds, some of the oxides are slightly soluble in liquid metals and later precipitate in the grain boundaries of the solidifying metals where they profoundly influence the properties of the metals.

11. There are several instances, however, as for example with the metals silver, platinum, and palladium, where oxygen seems to dissolve as the element. On its release during solidification it gives rise to the sudden spitting or sprouting that often occurs on the freezing surfaces of these metals, particularly silver. It is from a knowledge of the kinds of non-metallic elements in the metals, their mode of existence, and the manner in which they may be eliminated or rendered harmless that principles governing deoxidation and degasification of metals are established.

## PRINCIPLES GOVERNING SOLUBILITY OF NON-METALLIC ELEMENTS IN METALS

12. The distribution of non-metallic elements in solid and in liquid metals differs in degree, but not in kind. In solid metal the solubility of non-metallic elements increases linearly up to the melting point; in liquid metal their solubilities are usually greater and increase rapidly with the temperature. When in solution, their concentration is not directly proportional to their partial pressure in the surroundings but is proportional to the square root of the partial pressures. This indicates that these elements in solution must either dissociate into the atomic state upon absorption by the metal, or they are in solution as some simple compound with the metal. The ability of a metal to dissolve these elements should then depend on the ability of that metal to dissociate them or to form soluble compounds with them. It must

be admitted, however, that the relation between the absorbed elements and the metal is not perfectly clear.

13. The foregoing fundamental principle, known as the distribution law, expresses the ratio between the concentration of a given element in the metal and its concentration in the surrounding atmosphere. The union of the metal with simple gas molecules will not in any way alter the applicability of the simple law. But as the law leads to conclusions strictly applicable to ideal gases, and as gases depart somewhat from the ideal, it may fail at times to express exactly the distribution of the elements between the metal and surroundings. However, departures from the ideal are not of serious consequence.

## Hydrogen Solubility Varies

14. It was stated that the amount of gas absorbed by metals is dependent on the concentration of the gas in the surroundings; it is also dependent on the temperature. In most instances the solubility of hydrogen, oxygen, and other gaseous elements in solid metals increases proportionally with the temperature up to the melting point. There is an abrupt increase when the metal liquifies and further increased solubility as the temperature rises.

15. To cite examples, the solubility of hydrogen in copper increases about three times at the melting point; molten silver dissolves about ten times its volume of oxygen and gives it up again on solidifying, and platinum behaves like silver. On the contrary, the solubility of hydrogen in palladium decreases abruptly (nearly one-half) as the metal melts.

16. While it does not necessarily follow, in metals the solubility of non-metallic elements generally increases with increasing temperatures.

17. There is complete absence of a linear relation between the solubility of a gaseous element in an alloy and its solubility in the component metals. Hydrogen, for example, is virtually insoluble in silver, yet alloying silver with palladium raises the solubility until a maximum is reached for an alloy containing 40 per cent silver. At 266 degrees Fahrenheit this alloy dissolves four times as much hydrogen as pure palladium.

18. The ability of an alloy to dissolve non-metallic elements is then not determinable from solubilities in the component metals. Due to the great number of alloying combinations which make up the industrial nonferrous castings, the uncertainties governing

solubility in alloys of an element such as hydrogen or oxygen become almost unlimited. Under the circumstances it is not at all surprising that there should be differences in the behavior of alloys toward non-metallic elements, even when they are of the same general class. It is conceivable that average variations in compositions alone of some bronzes, brasses, aluminum, or die-casting alloys may at times be sufficient measurably to alter their contamination by non-metallic elements.

### METHODS FOR CONTROLLING SOLUBILITY

19. Were it not for the fact that there are means for altering and controlling solubility, the problem of producing sound castings would be exceedingly difficult. In practice, for example, the tendency toward unsoundness in copper ingots and castings is kept in check either knowingly or unknowingly by a careful control of the oxygen content. This has two principal effects; first, it maintains the partial pressure of the hydrogen in the surrounding atmosphere below some fixed value, and second, it reduces the solubility of hydrogen in copper. Serious gas cavities occur only when the oxygen content of the metal falls below a certain quantity. This is because the amount of hydrogen absorbed by copper rises as the oxygen falls and rises very rapidly with low oxygen content. Liberation of the hydrogen upon solidification, or the interaction between the hydrogen and copper oxide dissolved in the metal to form steam and its subsequent liberation, seems to account for the unsoundness in copper ingots or castings. An analogous mechanism would explain much of the unsoundness in other metals and their alloys.

20. From what has been said it becomes evident that the presence or absence of blow-holes and porosity, of inclusions, and of sweating in nonferrous castings are closely tied in with the melting and casting procedure, and the deoxidation and degasification practice. The importance of controlling the furnace atmosphere with its moisture and hydrogen contents is certainly obvious.

21. In practice it is becoming more generally accepted that atmospheres either neutral or slightly oxidizing to the metal or alloy in question are in the long run most satisfactory for melting. Reasons for this become apparent in the light of the inter-relation of the non-metallic element content of the metal to the composition of the surrounding atmosphere. Thus, for metals capable of absorbing noticeable quantities of hydrogen it may be advisable to

maintain the furnace slightly oxidizing to render the solubility of hydrogen in the metal as low as possible.

22. It does not follow from this, however, that reducing atmospheres are always detrimental in melting. Sound castings are being made daily from metal melted under the reducing atmospheres of electric furnaces. Conditions determine whether or not the reducing atmospheres will be detrimental. It is conceivable that an unusually dirty charge or one containing a high oxide content will be benefited through refining brought on as a result of chemical reduction of the impurities by the reducing gases. In addition, the principal reducing gas, carbon monoxide, is not soluble in some metals. Consequently, with the hydrogen content of the furnace atmosphere extremely low, so that it cannot contribute to the unsoundness, little or no harm may follow melting under reducing atmospheres.

## Furnace Atmosphere Is Important

23. The foregoing emphasizes the tremendous importance of furnace atmosphere control in obtaining sound nonferrous castings, whether the melting unit is heated by oil, gas, coke, or electric power. Unfortunately, it is still impossible to prescribe methods of melting or types of furnace atmospheres that are generally applicable for the melting of all kinds of alloys. So much is governed by other factors, such as character of the scrap and charge, composition of the metal, humidity of the atmosphere, and type of melting equipment that as yet the judgment of the operators must be relied upon to establish wise melting procedures in their respective plants.

24. But it is not alone the melting procedure that must be watched with care; there is also the interim from the moment the metal is taken from the furnace until it has solidified in the mold when much harm may be done through gas absorption and oxidation, unless the metal is properly protected. Changes in environment—that is, surrounding the metal with a different atmosphere from what it was exposed in the furnace—immediately upsets the balance established between the content of non-metallic elements of the metal and of the furnace atmosphere. Consequently, oxidation and gas absorption may be rapid when the metal is withdrawn from the furnace. Sometimes, within sand molds, metal that has been melted with the greatest care is harmed by contact with moisture and other mold gases to the extent where the casting surface is honeycombed with small pin-holes.

25. These phenomena relative to the solution of non-metallic elements during melting, pre-heating, pouring, and solidification of the metal are all manifestations of that fundamental principle known as the distribution law. Recognition of this principle leads to the control of the non-metallic elements and the elimination of their harmful influences in nonferrous metals.

## ELIMINATION OF HARMFUL INFLUENCES OF NON-METALLIC ELEMENTS

26. It is the sudden change in solubility at the melting point, which causes gas to be given off during solidification, that accounts for porosity in castings due to dissolved non-metallic elements.

27. To some degree the quantity of gas evolved depends on the rate of cooling. Because the gas is placed under pressure by the confining metal when it solidifies rapidly, it is possible to check blow-hole formation by severely chilling the castings. This is because the solubility of non-metallic elements is a function of the pressure. Hence, to cast sound metal free from blow-holes the hydrostatic pressure of the liquid metal should be kept greater than the greatest internal gas pressure.

28. This principle is interestingly illustrated by the perceptible reduction in zinc evolution from brasses by the presence of an aluminum film. The vapor pressure of zinc in brass is not greatly affected by the aluminum in the alloy. The skin of the molten alloy must therefore be under an appreciable stress in order that it reduce the zinc loss.

29. It was mentioned that the solubility of hydrogen in copper, for instance, is greatly reduced by the presence of oxygen. Both tin and zinc will reduce the solubility of hydrogen, carbon monoxide, and sulphur dioxide in copper, and phosphorus probably acts similarly. By altering the composition of the metal it is possible, sometimes, to reduce the internal gas pressure substantially. This principle governs the action of some deoxidants, and they may be regarded as additions which reduce the internal gas pressure below that at which the gas is released. How low this pressure need be is not always easy to determine. In the case of hydrogen, for example, a certain amount of supersaturation appears necessary before bubbles will form.

30. One function of deoxidizers has been referred to; others are of equal importance. Certain deoxidizers alter the nature of the oxides, transforming soluble ones into insoluble ones that rise or form relatively harmless emulsions. The third important func-

tion is to free the metal of those easily reduced oxides which react with certain components of the metal, during the latter's solidification, to form gaseous products. The reaction of copper oxide with hydrogen to form steam is one example. Here, the cause for porosity is the reaction between two soluble materials to produce an insoluble compound. The function of the deoxidizer is to remove the copper oxide, thus preventing the reaction from going forward.

31. While it appears possible to remove hydrogen from nonferrous metals by slight oxidation, attempts to do so may not be completely successful owing to the large excess of oxygen and length of time required for oxidation. The adjustment to equilibrium following changes in the composition of the surrounding atmosphere is slow, and more than equilibrium quantities of hydrogen may persist for some time. The velocity of reaction of this type, even at the temperature of molten metals, is slow.

### Hydrogen Eliminated by Pre-solidification

32. By utilizing the decreased solubility during solidification, more rapid reduction in hydrogen may be effected by pre-solidification, then remelting rapidly to the temperature for pouring the metal. This method has been successfully used on various nonferrous alloy castings. Care must be taken, however, to see that the metal is not contaminated again during the re-heating period.

33. Other means, based on the principle of the distribution law, are available for eliminating the soluble non-metallic elements from metals. The principle is utilized when chlorine or nitrogen is continually bubbled through or swept over the surface of molten metal to eliminate dissolved gases, and again it is applied in the vacuum method of melting. To a degree, both methods have lately received stimulation.

34. The same may be said of the use of fluxes, their purpose being to protect the surface of metal from the furnace gases. Not all fluxes will protect the metal when highly heated. Many of them are easily penetrated by hydrogen. To be useful they should be impenetrable to hydrogen and should be capable of dissolving the oxides in the metal.

35. While many schemes for eliminating the deleterious effects of non-metallic elements in nonferrous castings are suggested, they are mostly dependent on such fundamental conceptions as the change in solubility of the non-metallic elements in metals with temperature, concentration, and pressure, and furthermore, upon the change in solubility on the addition of other impurities.

# Deoxidation and Degasification of Red Brass and Bronze

**Abstract**

*This is a report prepared by the Committee of the A.F.A. Nonferrous Division on the deoxidation and degasification of red brass and bronze. The personnel of this committee consists of Chairman O. W. Ellis, Ontario Research Foundation, Toronto, Ont., Can.; J. W. Bolton, Lunkenheimer Co., Cincinnati; and E. R. Darby, Federal Mogul Corp., Detroit. The report is a continuation of the work presented at the 1933 convention and is made in an endeavour to present to the industry the underlying principles of the deoxidation and degasification of nonferrous casting alloys and a fuller understanding of the problems involved.*

1. That efficient deoxidation and degasification are essential for the production of sound castings of red brass and bronze is recognized by foundrymen everywhere. This Committee, therefore, need make no excuse for again leading the discussion of this important subject. Anything that can reduce waste and improve quality is worthy of note, and if, as a result of the conversations following this paper, further additions are made to our general or individual knowledge of the manufacture of sound metal, the Committee will feel amply rewarded for the time that it has devoted to this work.

2. If the metals with which we are concerned here did not react with the oxygen of the air to form oxides and did not dissolve certain of the gases under which they stand in the molten state, our troubles as foundrymen would be largely eliminated. Difficulties due to liquid and solid shrinkage and troubles due to volume changes at the freezing point, or within the freezing range, would be the most important factors with which we should have to contend.

3. But the facts that these metals do form oxides, and that with alacrity, and that they do absorb certain gases, and that

NOTE: This is one of the papers presented at the Symposium on Deoxidation and Degasification of Nonferrous Casting Alloys held at the 1934 Convention of the A. F. A.

with surprising speed, cannot be ignored so long as we continue to melt our metals in furnaces of the types now generally used.

## EFFECT OF OXYGEN

4. When *copper* is melted in air, it dissolves oxygen. This oxygen combines with some of the copper to form cuprous oxide, so that to all intents and purposes the melt may be looked upon as a solution of cuprous oxide in copper. If such a melt were prepared in an impervious, non-reactive crucible (*i.e.*, a crucible that would react neither with the melt nor with any gases absorbed in the melt), and if this crucible, together with the melt, were placed in an evacuated space so that (1) the gases absorbed in the melt could be removed and (2) the metal could then freeze out of contact with such gases as might be absorbed by it, a sound ingot would be obtained. The fact that the ingot contained cuprous oxide would not affect its soundness. In other words, oxygen alone cannot cause blowholes in copper.

5. If, while the melt of oxidized copper was in the vacuum, any of the elements, aluminum, lead, tin, zinc, boron, phosphorus, or silicon, were introduced into the crucible, reaction would occur between the cuprous oxide and the element introduced, with the result that an oxide of the element would be formed. This oxide would, in part, dissolve in the copper and, in part, separate from the copper under the action of gravity, the particles of oxide obeying Stokes' Law. If the melt were allowed to solidify in the crucible, the ingot would be found to have been freed from cuprous oxide (provided enough element had been added to the melt) and to be covered with a layer of the oxide of the added element, or to have disseminated throughout its mass, particles of the oxide of the added element distributed in accordance with Stokes' Law. The picture would be somewhat different if the oxide of the element were soluble in copper in the liquid state and insoluble in the solid metal. In no case, however, would the ingots be unsound.

## CARBON REACTS WITH CUPROUS OXIDE

6. If, while the melt of oxidized copper was in the vacuum, a carbon rod were used to stir the melt, the carbon would react

with the cuprous oxide to reduce it to metal in accordance with the equation

$$Cu_2O + C \leftrightarrows 2\ Cu + CO$$

If *all* the cuprous oxide were removed from the melt as a result of stirring, and if the metal were then allowed to freeze slowly enough, all the carbon monoxide would be rejected by the metal, and the resulting ingot of oxide-free copper would contain no blowholes. If, however, before the melt was allowed to freeze, only part of the cuprous oxide had been removed as a result of stirring (the carbon rod being removed), reaction would occur between the carbon monoxide and the unreduced cuprous oxide

$$CO + Cu_2O \leftrightarrows 2\ Cu + CO_2$$

so long as any liquid remaining in the solidifying ingot, with the result that numerous blowholes, tending to congregate in the neighborhood of those parts of the copper crystals last to solidify, would characterize the solid metal.

## ACTION OF SULPHUR

7. If, in place of a carbon rod, a stick of sulphur were used to stir the melt, the sulphur would react with the copper to form copper sulphide, ($Cu_2S$), which in turn would react with the cuprous oxide to reduce it to metal in accordance with the equation

$$Cu_2O + Cu_2S \leftrightarrows 6\ Cu + SO_2$$

If *all* the cuprous oxide were reduced to metal as a result of the treatment with sulphur, and the metal were then allowed to freeze, no matter at what rate, a porous ingot would be obtained because sulphur dioxide is soluble in liquid copper, but distinctly less soluble in the solid metal. And, whether all or part of the cuprous oxide were reduced, a porous ingot would be obtained on freezing, since sulphur dioxide would be formed and dissolved in the melt and would be rejected by the metal as it solidified.

8. Such reactions as the above, namely

$$Cu_2O + C \leftrightarrows 6\ Cu + CO$$

$$2\ Cu_2O + Cu_2S \leftrightarrows 6\ Cu + SO_2$$

can occur, of course, only if cuprous oxide is present in the copper. If, prior to stirring the melt in vacuum with the carbon rod or the sulphur stick, one or other of the metallic or non-metallic elements (Al, Pb, Sn, Zn, B, P, Si) referred to above had been added to the melt, and if the oxide formed as a result of its reaction with the cuprous oxide in the melt had been *removed,* the ingot result-

ing from the solidification of the melt would have been sound, since neither carbon monoxide nor sulphur dioxide would have been produced. However, had the new oxide ($Al_2O_3$, $PbO_2$, etc.) not been removed, and had it been able to react* with either the carbon or the sulphur with the formation of one or other of the gases named, unsound ingots would have been obtained.

9. If, while the solution of cuprous oxide in copper was molten, hydrogen had been allowed to enter the evacuated space, the solution would have absorbed hydrogen, which, during solidification of the metal, would have reacted with the cuprous oxide in accordance with the equation

$$Cu_2O + H_2 \leftrightarrows 2\ Cu + H_2O.$$

A porous ingot would have been obtained, in which the blowholes would have formed in the vicinity of those parts of the copper crystals last to solidify, *i. e.*, in those parts where the cuprous oxide had become concentrated during freezing.

## HYDROGEN UNSOUNDNESS

10. If, prior to allowing hydrogen to enter the evacuated space, one or other of the elements, aluminum, lead, etc., had been allowed to react with the cuprous oxide in the melt, and if the new oxide ($Al_2O_3$, $PbO_2$, etc.) had been removed, the ingot resulting from the solidification of the melt would have been sound, provided its rate of cooling had not been too rapid. Had this rate been fast, a very characteristic porosity ("hydrogen unsoundness") would have resulted—a porosity due entirely to the fact that hydrogen is more soluble in liquid than in solid copper.

11. If the new oxide had not been removed from the melt, the ingot resulting from its solidification would have been porous or non-porous according as the new oxide could or could not react with the hydrogen to form steam.

## DISCUSSES EFFECT OF TIN

12. When tin is added to copper containing cuprous oxide, the following reaction occurs:

$$2\ Cu_2O + Sn = SnO_2 + 4\ Cu$$

Daniels has suggested[1] that this reaction is a balanced reaction

* It seems unlikely that alumina ($Al_2O_3$) or silica ($SiO_2$) would react in this way.

[1] Daniels, E. J., *"Unsoundness in Bronze Castings,"* JOURNAL INSTITUTE OF METALS, (British), vol. 43, pp. 125-142, (1930).

and should, therefore, be written as follows:

$$2\ Cu_2O + Sn \leftrightarrows SnO_2 + 4\ Cu$$

Hence, according to his theory (which involves the assumption that tin oxide is practically insoluble in molten bronze), both tin oxide ($SnO_2$) and copper oxide ($Cu_2O$) will be present in straight bronze (bronze devoid of elements other than copper and tin), their active masses in the liquid metal being constant. Hydrogen present in a furnace atmosphere would, therefore, be absorbed by molten bronze and would, as the melt solidified and it was thrown out of solution, react with the precipitating cuprous oxide to form steam in accordance with the equation:

$$Cu_2O + H_2 \leftrightarrows H_2O + 2\ Cu$$

According to Daniels, then: "It is possible that normally occurring unsoundness is due to the combined presence of hydrogen and oxygen in the molten bronze."

13. However, Daniels' suggestion that an appreciable amount of cuprous oxide can be present in brass or bronze does not meet with much favor. One would judge that most metallurgists believe that when tin is added to oxidized copper in sufficient amount, *all* but the least trace of cuprous oxide is reduced to metal, tin oxide ($SnO_2$) being formed, and that when zinc is added to oxidized copper in sufficient amount, *all* but the least trace of cuprous oxide is reduced to metal, zinc oxide (ZnO) being formed. In other words, the reactions

$$2\ Cu_2O + Sn \leftrightarrows SnO_2 + 4\ Cu$$

$$Cu_2O + Zn \leftrightarrows ZnO + 2\ Cu$$

to all intents and purposes go to completion. The question whether tin oxide is soluble in bronze remains to be answered; there seems little doubt, however, that zinc oxide is soluble in molten brass and bronze, in view of the fact that the size of zinc oxide particles in castings varies according to the rate of freezing of the alloy in which they are formed—the greater the rate of freezing, the smaller the particle size.[2]

14. That hydrogen is soluble in molten bronze and that it is thrown out of solution as the alloy freezes has been shown by Daniels. The possibility does exist, therefore, that dissolved hydrogen and *zinc* oxide, when in process of rejection from a solidifying melt of bronze, will react to form steam with consequent formation of blowholes. And the further possibility remains that

[2] Ellis, O. W., *"Oxides in Brass,"* TRANSACTIONS, INSTITUTE OF METALS DIV., A.I.M.E., (1930) pp. 316-332.

dissolved hydrogen and *tin* oxide, when in process of rejection from a solidifying melt, will react to form steam, with consequent formation of blowholes.

## UNSOUNDNESS DUE TO REACTIVE OXIDES

15. A consideration of the above discussion will make it clear that, were no oxides present in copper, brass, or bronze, no reactions involving the formation of steam or sulphur dioxide could occur, and, further, that were non-reactive oxides present, no such reactions could happen. Only when reactive oxides are retained in the metal, can unsoundness due to steam or sulphur dioxide be looked for.

16. There is some justification, then, for the use of the term "oxidized" metal. But whether "oxidation" is the most common cause of sponginess and porosity is open to question.

17. The fracture of so-called "oxidized" red brass or bronze is quite characteristic. It has a dark-red to chocolate color, quite different from that of the fracture of sound metal. Foundrymen have noted that some alloys are more prone to "oxidation" than others. In general, the high-copper red brasses (e. g., 85-5-5-5) and the tin bronzes seem to be more readily affected than alloys of lower copper content.

## METAL RIDDLED WITH FISSURES

18. Polished samples of "oxidized" red brass and bronze have a characteristic appearance when examined under the microscope. The porosity of the metal is thus clearly revealed and its true nature demonstrated. The metal is found to be riddled with intercrystalline fissures, more or less coarse.

19. At one time these fissures were presumed to be filled with oxides, but Comstock[3], as a result of his studies of non-metallic inclusions in bronze and brass, arrived at the conclusion that: "The oxide films so frequent in commercial bronzes may be caused either by the volatile oxides of zinc or phosphorus or by dissolved gases thrown out of solution when the metal solidifies." In any event, the fissures were not segregations of oxide.

20. Woyski and Boeck[4], at a later date, suggested that: "Gas and shrinkage cause porous metal and intercrystalline fissures."

[3] TRANSACTIONS, A.I.M.E., (1919), vol. 60, p. 386.
[4] TRANSACTIONS, A.I.M.E., (1923), vol. 68, p. 861.

They believed that defects due to gas and shrinkage had an appearance similar to those caused by "oxidation" and were often wrongly diagnosed. That so-called "oxidation" was, in reality, caused by gas and shrinkage apparently did not present itself to them as a possibility.

## INCIPIENT SHRINKAGE

21. Bolton and Weigand[5] were the first to place on record the opinion that the porosity of "oxidized" red brass and bronze was due to intercrystalline fissures, not, of necessity, *filled* with oxide. Further, they produced abundant evidence in support of the view that these intercrystalline fissures were identical in nature with, though smaller in scale than, the shrinkage cavities with which foundrymen were already so well acquainted. Each intercrystalline fissure, they opined, was a microscopic shrinkage cavity. The surface of such a cavity might or might not be coated with a film of oxide, according to whether the gas which evolved within, or seeped into, the cavity during or after its formation was oxidizing or not. If a preponderance of these microscopic cavities became filmed with oxide (a film of oxide such as forms on metal when heated for a short time in air), the fracture of the metal would be dark-red to chocolate in hue. It would be "oxidized" metal.

22. To this type of porosity Bolton and Weigand gave the name "incipient shrinkage," a term now in general use among American metallurgists.

23. As to the cause or causes of "incipient shrinkage" opinions differ. It is generally admitted that severe oxidation increases the tendency of metal toward incipient shrinkage, while melting under reducing atmospheres causes its appearance, often in aggravated form (*e. g.*, with slow melting and/or excessive furnace temperatures). The defect is exaggerated in castings which have been insufficiently gated or poured at too low a temperature. The presence of aluminum or of silicon in the metal seems to increase the chance of trouble due to this phenomenon, though the question may well be asked whether or not the disease caused by the presence of these elements in the molten bronze is identical in its nature and origin with that which appears in their absence.

[5] TRANSACTIONS, INSTITUTE OF METALS DIVISION, A.I.M.E., (1929), p. 475, and (1930), p. 368.

24. In the light of the discussion which terminated with paragraph 15, one is led to conclude that severe oxidation *alone* would not cause incipient shrinkage, unless, perchance, such oxidation tended to prevent the "feeding" of a casting during its solidification. On the other hand, the fusion under a reducing atmosphere of oxide-free red brass or bronze *alone* would not cause incipient shrinkage. In general, it is the fusion of alloys containing reactive oxides in a reducing atmosphere, or in one containing sulphur, that results in incipient shrinkage and "oxidized" metal (*i. e.*, metal characterized by fractures dark-red to chocolate in hue). However, the important possibility that alloys devoid of oxides may suffer from "hydrogen unsoundness" or porosity of a similar nature (due to other reducing gases) must not be overlooked.

## FACTORS MAY BE CONTROLLED

25. Fortunately, the proportions of reactive oxides and the compositions of furnace atmospheres are subject to control. By carefully choosing the ingredients of the charge, by limiting (as may be done in many furnaces) the formation of oxides during the first stages of melting, and by the use of suitable fluxes, the proportions of reactive oxides in a given melt can be reasonably regulated. A well-balanced discussion of how these things may be accomplished in open-flame furnaces has been published by Darby[6], from whose paper the following important sentence is taken: "It would appear then that a slight amount of oxide in the metal is essential to the production of sound castings from open-flame furnaces, when the metal to be melted is of the kind here considered."

26. This remark is thought to be important because it affirms an opinion which has been emphasized by numerous observers and aptly expressed by Daniels in the following terms: ". . . correct adjustment of oxide and gas in bronze will lead to the production of satisfactory castings." How to effect the correct adjustment is *the* problem of the foundryman.

## ADVANCES POSSIBILITIES

27. Why aluminum and silicon, such powerful deoxidizers, should have so remarkable an effect on red brass and bronze has yet to be shown. Both elements increase the amount of contrac-

[6] TRANSACTIONS, INSTITUTE OF METALS DIVISION, A.I.M.E., (1930), p. 407.

tion which occurs during the solidification of red brass and bronze, and both seem to encourage incipient shrinkage. However, this is not surprising, since one would expect that liquid contraction and incipient shrinkage would go hand in hand; the greater the one, the greater the other.

28. Insofar as aluminum is concerned, the ready formation of a "skin" on melts treated with this metal is an undesirable phenomenon, which may or may not have some bearing on incipient shrinkage in alloys containing it. The same may be true of alloys containing silicon. Generally speaking, the intercrystalline cavities in bronzes suffering from incipient shrinkage are covered with a film of "oxide" of a dark-red to chocolate hue. Is it not possible that as such cavities form, a reaction occurs between the metal lining them and the steam and/or sulphur dioxide which are released from the freezing melt:

$$2\ Cu + H_2O \leftrightarrows Cu_2O + H_2$$
$$6\ Cu + SO_2 \leftrightarrows 2\ Cu_2O + Cu_2S$$

Further, is it not possible that the "oxide" film which forms on the linings of such cavities will vary in color, other things being equal, according to the elements in solution in the brass or bronze? If these things are possible, then the characteristic colors of the fractures of alloys to which aluminum or silicon have been added may be explained. To sum up, these elements increase the contraction which occurs on freezing, aggravate incipient shrinkage when the conditions (oxide content of melt and composition of furnace atmosphere) conduce to this defect, and modify the reaction of the alloy to steam and/or sulphur dioxide, thus giving to its fracture a characteristic hue.

## EFFECT OF POURING TEMPERATURE

29. So far, the effect of pouring temperature upon the incidence of incipient shrinkage has not been discussed. In closing, then, brief reference may be made to this important factor. In general, the higher the pouring temperature, the less the density and the lower the Brinell hardness numbers of the alloys under discussion. However, their tensile strengths do not vary in proportion to their Brinell hardness numbers. Maximum strength in these alloys, then, does not connote maximum density. This is an important point that is occasionally overlooked. The phenomena have yet to be satisfactorily explained, though some thought might

well have been given to the distribution and type of porosity in tensile test pieces used in investigations reported on to date. How little we know, and how much we have yet to learn!

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# Deoxidation and Degasification of Yellow Brass

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**Abstract**

*The author has divided this paper into two parts. The first deals with deoxidation and the second with degasification of yellow brass. In discussing deoxidation, the author reviews the effects of various elements present in yellow brass, such as copper, zinc, tin, lead. He also outlines the effects of such deoxidizers as aluminum, silicon, manganese, phosphorus, lithium. calcium, etc., with regard to the formation of oxides that may be present in the melt. He reaches the conclusion that various deoxidizers are unnecessary and merely confer fluidity on the metal. Under degasification, the author gives three sources of gases in castings and points out the importance of the solubility of these gases at pouring temperatures and in the solid metal. He arrives at the conclusion that the best method of degasification probably is pouring the metal at as low a temperature as possible. A table accompanies the paper which shows the results of various deoxidizers and varying pouring temperatures on the physical properties of the castings.*

1. A symposium, such as the one of which this paper is a part, is worthwhile and valuable not only for the information gained but for the discussion which it provokes, and for provoking clear analysis of brass foundry problems. Often we live so closely with these problems that our analysis of them falls into a rut out of which we can climb only by putting down all the facts we know and analyzing each one separately. In this way, we can get a fresh view point and see where we have erred.

2. This paper, then, will outline briefly the salient facts known and then analyze them to find how best to deoxidize and degasify yellow brass. This paper is divided into two parts, the first dealing with deoxidation and the second with degasification.

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Note: This is one of the papers presented at the Symposium on Deoxidation and Degasification of Nonferrous Casting Alloys held at the 1934 Convention of the A. F. A.

By yellow brass, is meant, for the purposes of this paper, a brass of not more than 75 per cent copper, consisting essentially of copper and zinc but with the permissable addition of lead, tin and small amounts of other alloying metals.

## PART I—DEOXIDATION

3. What oxides can be present in yellow brass? It is necessary to consider the oxides of all the elements present and see whether or not they can be present. If they can be present, it is then necessary to consider whether this is probable.

4. COPPER—The first to be considered is copper oxide or, more properly, cuprous oxide. If we make a brass using virgin metal, in all probability the copper will be melted first and then the zinc will be added. In this primary melting of the copper, some cuprous oxide undoubtedly will exist. The question then is whether or not this would be reduced on the addition of zinc. Zinc is a very powerful reducing agent and there is no doubt that it can and does reduce any cuprous oxide that may be present.

5. If, then, there is no possibility of having cuprous oxide present, what of the other oxides? Zinc being the only other major constituent present, its oxide should be considered next.

6. ZINC—Zinc is readily oxidized under ordinary melting conditions but zinc oxide does not dissolve readily in the brass and therefore if it is present most of it is simply mechanically entrapped. That such is the case has been shown by such workers as O. W. Ellis, who reported on the amount of zinc oxide present due to varying melting conditions and analyses. Lumps of this oxide often become disengaged and fall into the melt where a portion of them are broken up into fine particles. It has been shown that these particles are so fine that they can not be separated from the melt by gravity and hence can not be removed by skimming.

7. Ellis also called attention to the practice of many foundries using barrel-type furnaces, of filling the furnace full of scrap and sometimes even heaping it up outside the door. Wholesale oxidation of the brass certainly takes place under these conditions, no matter how reducing the flame may be or how well the molten metal is kept covered by charcoal or a slag. Very probably, brass melted under such conditions would contain much zinc

oxide and therefore certainly would not be suitable for producing high grade sand castings.

8. TIN—Tin is one of the minor constituents that may be present. Tin is added to brass either in the scrap used or as the metal itself. If it is added in the scrap, zinc probably will be present so the tin will not be oxidized. When added as the metal, tin usually is added after the zinc and therefore will not tend to oxidize. Any tin oxide in the melt will be present due to oxide already on the tin before adding it to the brass and the amount present will be negligible.

9. LEAD—Lead is another of the minor constituents that is frequently present. If scrap containing lead is melted, there is a possibility that some of the lead would become oxidized during the early stages of the melting. This oxide might be retained in the melt as physically entrapped particles much as zinc oxide is. It is the opinion of the writer that the amount present will be negligible.

## INFLUENCE OF OXIDES OF DEOXIDIZERS

10. Oxides of deoxidizing agents used may be present. When using aluminum, silicon, or manganese, the oxides certainly are retained and in some cases seriously affect the quality of the castings.

11. ALUMINUM—It is a well recognized fact that brass castings in which aluminum is used as a deoxidizer are unsound, and fractures of these castings often show quite large particles of aluminum oxide present. This is shown clearly in Fig. 1, the photograph of a fractured rod which was deoxidized with aluminum. Distribution of the small particles of aluminum oxide are shown in Fig. 2, the photomicrograph at 500x of a cast brass rod deoxidized with aluminum.

12. SILICON—Silicon also is oxidized and the oxide is retained in the casting as finely divided silicon dioxide. The oxides of both aluminum and silicon, if present in the casting, will make the brass difficult to machine and necessitate frequent grinding of tools.

13. MANGANESE—Manganese is often used as a brass deoxidizer and in many cases proves useful. At times, however, the manganese is oxidized to manganese dioxide and is retained in such a fine state of subdivision that it can not be removed and on solidification of the casting is precipitated in the grain boundaries.

Such was the case in a recent casting series of 75 per cent copper, 4 per cent lead brasses deoxidized with various agents. In the case of the manganese deoxidized castings poured at 1800 degrees Fahr., the tensile strength was 27,000 lbs. per square inch. These castings showed a clean dense structure on fracturing. When the pouring temperature was raised above 2000 degrees Fahr., the tensile strength dropped to 14,000 pounds per square inch and a fracture showed very large radial crystals completely surrounded by a thin film of manganese dioxide, dark brown in color.

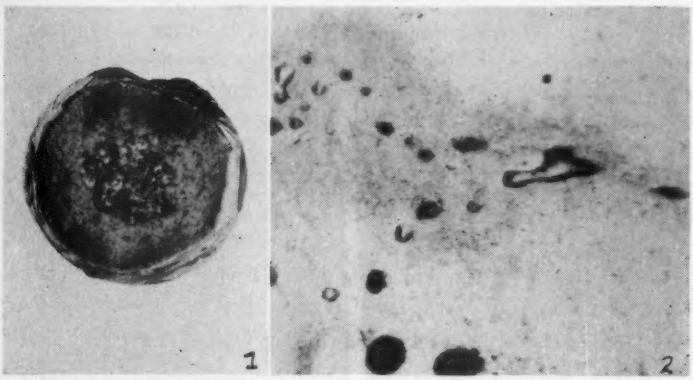


FIG. 1—FRACTURE OF CAST YELLOW BRASS ROD DEOXIDIZED WITH ALUMINUM, SHOWING ALUMINUM OXIDE INCLUSIONS. BRASS CONTAINS 60 PER CENT COPPER, 4 PER CENT LEAD, 0.2 PER CENT ALUMINUM AND REMAINDER ZINC. FIG. 2—MICROGRAPH AT 500X SHOWING ALUMINUM OXIDE PARTICLES IN YELLOW BRASS ROD DEOXIDIZED WITH ALUMINUM. ETCHED WITH $NH_4OH$ PLUS $H_2O_2$. BRASS CONTAINED 75 PER CENT COPPER, 4 PER CENT LEAD, 0.1 PER CENT ALUMINUM AND REMAINDER ZINC.

14. PHOSPHORUS, LITHIUM; CALCIUM, ETC.—This leaves, as suitable deoxidizers of brass, only phosphorus, lithium, calcium, etc. Phosphorus when oxidized passes out of the metal as a gas. Little or no work has been done on the use of lithium or calcium as deoxidizers of brass. They are used extensively for copper with excellent results and if it is possible to judge by these results, they should prove to be some of the most satisfactory deoxidizers available for brass.

15. How, then, shall brass be deoxidized? In the first place, deoxidization of yellow brass, as we usually think of it, is unnecessary. With the amount of zinc that is present, it is impossible to have any copper oxide present and none of the common deoxidizing agents would reduce the oxides of zinc, lead and

tin that would be present. This being true, what is the actual function of the common deoxidizers? For the most part, they are what might be termed fluidizers. They may also, by changing the equilibrium, function as degasifiers, but that use does not rightfully belong in this section of this paper.

16. Aluminum, although harmful in many ways, often is useful in the brass foundry as an aid in getting sharp impressions in castings where there are no pressure requirements. When used this way great care must be taken that, through carelessness, other mixtures are not contaminated. As to its effects on the casting other than those cited, it increases the grain size and makes it possible to use lower pouring temperatures due to the increase in fluidity. This increase in grain size is shown in Figs. 3-a and 3-b, macrographs of the two bars of 75 per cent copper, 4 per cent lead brass cast at 2000 degrees Fahr. The one contained no deoxidizing agent and the other 0.9 per cent aluminum.

### PHOSPHORUS INCREASES FLUIDITY

17. Phosphorus, like aluminum, also increases the fluidity of the molten brass and the metal takes a much sharper impression in the mold. Unlike the aluminum, it does not show a tendency to increase the grain size of the casting when the temperature is held the same.

18. Silicon has the same property of rendering the metal more fluid when used as a deoxidizer and like aluminum tends to increase the grain size. Physical properties at the various casting temperatures show the same tendency as with phosphorus; namely, that at a low casting temperature the presence of silicon is beneficial, while at the higher temperatures it is detrimental, if anything.

19. The results of these casting series which are mentioned above are shown in Table I. Macrographs from these series are also shown in Figs. 3-a, b, c, and d. The differences in grain size due to deoxidizers are clearly shown in these illustrations.

20. One method of deoxidization that is most important is the proper control of melting condition and the protection of the metal during melting by slags or charcoal. Sound castings with a minimum of oxide inclusions can be made using any of the commercial melting furnaces if controlled properly. The atmosphere should be kept neutral or slightly reducing and the charge should

be added only as fast as it can be melted with the proper protection.

21. As to the benefits derived from the use of slags or charcoal, there are ardent advocates of both and good clean metal may be produced with either. When large amounts of scrap, particularly dirty scrap, are being melted a slag cover usually gives superior results since it does remove a large proportion of the foreign material by dissolving it and therefore aids the caster to skim the pot clean.

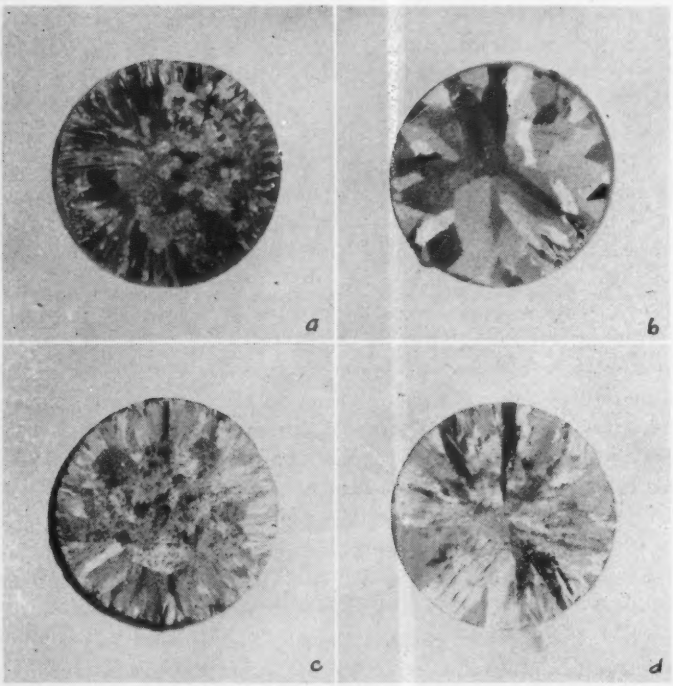


FIG. 3—MACROGRAPHS AT 1½X OF YELLOW BRASS RODS SHOWING THE EFFECT OF ALUMINUM, PHOSPHORUS AND SILICON ON GRAIN SIZE. ETCHED WITH NITRIC ACID. *a*, ROD IN WHICH NO DEOXIDIZER WAS USED. *b*, ROD IN WHICH 0.09 PER CENT ALUMINUM WAS USED AS A DEOXIDIZER. *c*, ROD DEOXIDIZED WITH PHOSPHORUS. *d*, ROD DEOXIDIZED WITH SILICON. ALL RODS CONTAINED 75 PER CENT COPPER, 4 PER CENT LEAD AND REMAINDER ZINC. IN ADDITION, *b* CONTAINED 0.1 PER CENT ALUMINUM, *c*, 0.01 PER CENT PHOSPHORUS AND *d*, 0.15 PER CENT SILICON.

## PART II—DEGASIFICATION

22. A study of degasification of brass should include the effect of following gases: Hydrogen, steam, air, nitrogen, carbon monoxide, carbon dioxide and methane.

23. From the literature, brass foundrymen are particularly interested in the first three. The others either definitely are not soluble in the molten brass or only slightly so.

24. Any gases present in the castings are from one of three sources:

1. They may have been present in the metal going into the charge and may have been retained through the melting and casting cycle.
2. They may have been dissolved during the melting process.
3. They may have become entrapped in the molten metal in the mold.

25. Further, we are not interested, primarily, in the solubility of the gases either in the molten or solid metal. It is immaterial how much gas dissolves during melting if it all stays in solution when the casting solidifies, but if the gas that is dissolved during casting is not soluble in the solid metal, trouble will be experienced with porous castings.

### GAS SOLUBILITY IS IMPORTANT

26. Of the three more important gases listed above, the first two are soluble in the molten brass and only slightly so, if at all, in the solid metal. Hydrogen may be derived from cathode copper, which contains large volumes of it, or possibly from the furnace gases. Steam can be derived from wet scrap charged into the furnace, from the furnace atmosphere or from the gases present in the mold.

27. The solubility of both these gases decreases with a decrease in the temperature of the molten metal so that the best method of degasification which we have is to keep the casting temperature as low as is consistent with good casting practice. Proper venting of the molds, so that gases released during cooling of the molten metal in the molds can escape, is also of vital importance in degasification.

28. Proper control of furnace atmosphere, in the case of fuel fired furnaces, to keep the hydrogen content of the gases at a minimum is also important. It is at this point that the use of

covering agents on the molten metal becomes particularly useful. Slag coverings that prevent the furnace gases from coming into contact with the molten metal are especially good in many instances since they protect the metal by means of a liquid film, while charcoal can only protect by means of the gas mantle which it forms.

29. Air is referred to as one of the important gases with which we have to contend. Too violent stirring of the metal in the pot before pouring or too turbulent a stream in pouring will entrap air. Other sources of entrapped air are poor design of the mold, inadequate venting and sometimes too hard ramming of the cope.

### CASTING TEMPERATURE CONTROL NECESSARY

30. Even a well designed mold, if not poured correctly, will produce castings with blow holes especially if the casting temperature is low. Of equal importance is proper venting of the mold. Adequate venting of the mold can not be over emphasized since the lack of it is undoubtedly one of the most serious causes of unsoundness of castings. With inadequate venting the gases entrapped in pouring can not escape, nor can the steam and other gases generated in the mold due to the molten metal. Under such conditions, blow holes and often serious cold shots will form.

31. In a previous part of this paper mention was made of the use of fluidizing agents or deoxidizers as an aid in degasification. By making the metal more fluid, they aid by allowing the gas to escape more freely and also by making it possible to use lower pouring temperatures at which the gas is less soluble.

32. To degasify brass, then, we must look not so much to some abstruse or difficult procedure but rather to the obvious but often overlooked details.

33. Care should be taken in the melting to keep the atmosphere neutral or slightly reducing and to protect the metal from the flame by some covering material in so far as possible. Mold design and pouring conditions should be carefully studied to avoid entrapping gases in the metal and to give them a chance to escape if they do become entrapped.

34. The temperature should be kept as low as possible to lower the solubility of gases in the metal. The effect of temperature on the formation of blow holes is clearly shown in Figs. 4-a, b, c and d. These illustrations show fractures of cast rods poured

at different temperatures. It will be noticed in these that the metal is sound at the lower temperature and unsound at the high.

35. Table 1 showing physical properties of three series of alloys using different deoxidizers and varying pouring temperatures should prove of interest here, not so much for the absolute values obtained as for the comparisons shown with varying conditions. Each value shown is the average of at least two determinations on bars cast at different times. All the melts were made in a laboratory size Hoskins electric furnace of the resistor type. Scrap of known analysis and history was used, virgin metal being added to adjust the analysis. A charcoal covering was

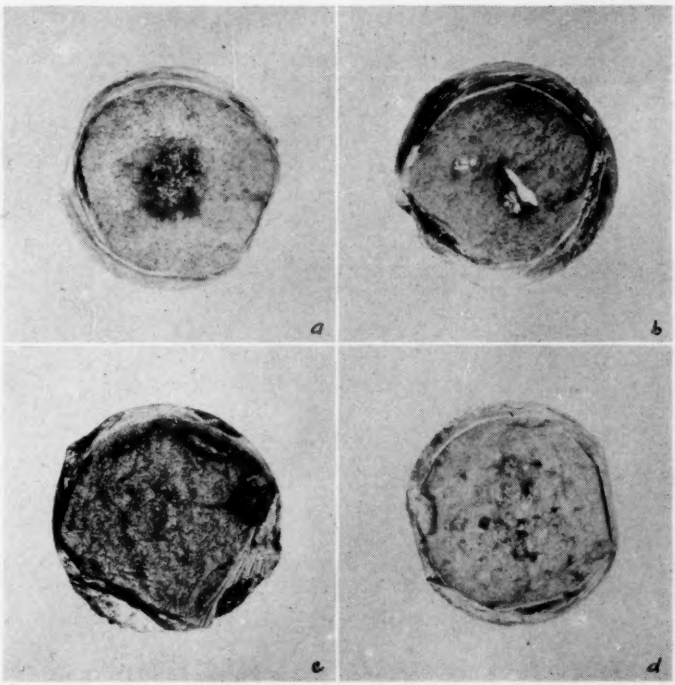


FIG. 4—FRACTURED YELLOW BRASS RODS SHOWING THE EFFECT OF CASTING TEMPERATURE ON THE FORMATION OF BLOW HOLES. *a*, YELLOW BRASS ROD CONTAINING 60 PER CENT COPPER, 4 PER CENT LEAD, 0.2 PER CENT ALUMINUM AND REMAINDER ZINC, CAST AT 1900 DEGREES FAHR. *b*, SAME BRASS CAST AT 2000 DEGREES FAHR. *c*, YELLOW BRASS ROD CONTAINING 60 PER CENT COPPER, 4 PER CENT LEAD AND REMAINDER ZINC, CAST AT 1700 DEGREES FAHR. *c*, SAME BRASS CAST AT 2000 DEGREES FAHR.

**Table 1**

## EFFECT OF CASTING TEMPERATURES AND DEOXIDIZERS ON PHYSICAL PROPERTIES OF YELLOW BRASS

| Alloy Number | Casting Temperature | Copper Per cent | Lead Per cent | Tin Per cent | Iron Per cent | Other Elements Per cent | Specific Gravity | Tensile Strength Lbs. per Sq. In. | Elongation in 2" Per cent | Izod Impact Strength Ft. Lbs. | Machinability[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1700 | 60.15 | 4.40 | | 0.02 | | 8.51 | 33,300 | 18.0 | 4.5 | 106. |
| | 1900 | 61.18 | 2.49[1] | | 0.03 | | 8.44 | 41,350 | 30.0 | 9.0 | 109. |
| | 2000 | 60.44 | 3.66 | | 0.03 | | 8.41 | 37,000 | 24.5 | 7.0 | 109. |
| 2 | 1700 | 61.72 | 3.89 | 1.98 | 0.02 | | 8.50 | 25,300 | 2.5 | 2.0 | 75. |
| | 1900 | 60.47 | 4.18 | 2.05 | 0.02 | | 8.52 | 38,800 | 7.0 | 2.0 | 74. |
| | 2000 | 60.33 | 4.09 | 1.97 | 0.03 | | 8.34 | 37,400 | 6.0 | 2.0 | 73. |
| 3 | 1700 | 59.82 | 3.86 | | 0.02 | 0.24 Al | 8.48 | 47,300 | 27.5 | 7.0 | 88. |
| | 1900 | 60.08 | 3.33[1] | | 0.04 | 0.18 Al | 8.43 | 47,800 | 31.0 | 8.0 | 91. |
| | 2000 | 59.43 | 4.56 | | 0.04 | 0.18 Al | 8.50 | 49,050 | 40.5 | 7.7 | 87. |
| 4 | 1700 | 60.89 | 3.35[1] | | 0.01 | 0.009 P | 8.46 | 39,550 | 27.5 | 8.0 | 102. |
| | 1900 | 60.43 | 3.92 | | 0.02 | 0.011 P | 8.40 | 34,025 | 25.0 | 7.0 | 105. |
| | 2000 | 59.28 | 5.01[1] | | 0.02 | 0.009 P | 8.41 | 32,300 | 17.5 | 7.0 | 113. |
| 5 | 1700 | 59.87 | 3.95 | | 0.02 | 0.094 Si | 8.41 | 46,600 | 29.0 | 6.5 | 94. |
| | 1900 | 58.97 | 3.83 | | 0.02 | 0.163 Si | 8.35 | 42,750 | 22.5 | 7.0 | 87. |
| 6 | 1700 | 58.75 | 4.52 | | 0.02 | 0.17 Mn | 8.49 | 42,500 | 25.0 | 7.6 | 91. |
| | 1900 | 58.84 | 4.32 | | 0.02 | 0.15 Mn | 8.44 | 41,850 | 29.0 | 7.5 | 92. |
| 7 | 1800 | 67.74 | 4.25 | | 0.02 | | 8.54 | 25,975 | 42.0 | | 113. |
| | 2000 | 68.46 | 3.40 | | 0.02 | | 8.37 | 25,950 | 40.0 | 6.5 | 113. |
| | 2100 | 68.08 | 4.74 | | 0.02 | | 8.25 | 19,600 | 24.0 | | 113. |
| 8 | 1800 | 74.85 | 4.17 | | 0.02 | | 8.63 | 18,600 | 14.0 | 5.0 | 123. |
| | 2000 | 75.35 | 4.07 | | 0.02 | | 8.68 | 26,700 | 28.0 | 9.0 | 105. |
| | 2200 | 75.46 | 4.03 | | 0.02 | | 8.45 | 19,200 | 19.0 | 6.1 | 105. |
| 9 | 1850 | 75.13 | 4.30 | 2.03 | 0.02 | | 8.65 | 24,450 | 18.0 | 4.7 | 94. |
| | 2000 | 75.77 | 4.19 | 2.03 | 0.02 | | 8.16 | 21,300 | 18.5 | 4.0 | 104. |
| | 2200 | 76.70 | 4.10 | 2.01 | 0.02 | | 8.00 | 14,900 | 15.0 | 3.5 | 100. |
| 10 | 1800 | 74.92 | 4.19 | | 0.01 | 0.08 Al | 8.65 | 31,250 | 30.5 | 6.5 | 104. |
| | 2000 | 75.62 | 4.00 | | 0.01 | 0.08 Al | 8.70 | 26,000 | 22.5 | 8.7 | 100. |
| | 2150 | 74.97 | 4.20 | | 0.01 | 0.12 Al | 8.67 | 24,550 | 28.5 | 8.5 | 127. |
| 11 | 1800 | 76.45 | 4.28 | | 0.03 | 0.008 P | 8.67 | 27,850 | 35.0 | 6.5 | 111. |
| | 2000 | 75.30 | 4.15 | | 0.02 | 0.011 P | 8.51 | 24,150 | 27.0 | 7.7 | 111. |
| | 2200 | 76.32 | 4.06 | | 0.02 | 0.003 P | 8.21 | 14,800 | 13.5 | 3.7 | 120. |
| 12 | 1800 | 75.06 | 4.14 | | 0.02 | 0.189 Si | 8.68 | 27,500 | 30.0 | 8.0 | 108. |
| | 2000 | 75.20 | 4.19 | | 0.02 | 0.156 Si | 8.44 | 16,150 | 26.0 | 6.0 | 105. |
| | 2200 | 75.40 | 4.33 | | 0.02 | 0.165 Si | 8.36 | 15,180 | 16.5 | 4.5 | 107. |
| 13 | 1800 | 74.80 | 3.78 | | 0.03 | 0.17 Mn | 8.70 | 26,975 | 18.0 | 7.0 | 114. |
| | 2000 | 74.90 | 4.05 | | 0.03 | 0.18 Mn | 8.51 | 23,075 | 23.0 | 7.3 | 105. |
| | 2200 | 76.09 | 3.45 | | 0.03 | 0.14 Mn | 8.24 | 14,130 | 17.5 | 6.0 | 111. |
| 15 | 1800 | 75.17 | 4.32 | 2.73 | | 0.085 Al | 8.61 | 25,430 | 17.7 | 5.4 | 110. |
| | 2000 | | | | | | 8.58 | 23,950 | 19.0 | 6.7 | 103. |
| | 2100 | | | | | | 8.57 | 23,275 | 19.0 | 6.4 | 107. |
| 16 | 1800 | 75.07 | 4.43 | 2.70 | | 0.005 P | 8.61 | 30,025 | 24.2 | 5.1 | 101. |
| | 2000 | | | | | | 8.55 | 30,025 | 25.2 | 5.2 | 104. |
| | 2200 | | | | | | 8.44 | 28,650 | 25.5 | 4.9 | 111. |
| 17 | 1800 | 75.55 | 4.50 | 2.82 | | 0.15 Si | 8.62 | 25,400 | 20.5 | 4.3 | 108. |
| | 2000 | | | | | | 8.46 | 23,425 | 20.0 | 5.0 | 108. |
| | 2100 | | | | | | 8.43 | 18,830 | 13.5 | 4.6 | 108. |
| 18 | 1800 | 74.82 | 4.41 | 2.73 | | 0.14 Mn | 8.60 | | | 5.0 | 116. |
| | 2000 | | | | | | 8.43 | 26,500 | 26.2 | 4.2 | 120. |
| | 2100 | | | | | | 8.55 | 23,025 | 24.0 | 4.9 | 112. |

[1] Lead badly segregated.

[2] Machinibility expressed as ratio of Machinibility of free turning brass rod to machinability of sample, Hard-drawn, free-turning brass rod was used as standard and its machinability considered as 100 per cent.

used in every melt and every possible precaution was taken to insure the reliability of the results.

## CONCLUSION

36. In conclusion, this paper may be summarized by saying that with care in melting and casting, no deoxidizing agent is necessary and that the best method of degasification is to keep the casting temperature as low as possible and use care in melting and pouring the brass.

## ACKNOWLEDGMENT

37. The writer desires to thank the Chase Brass & Copper Co. for permission to publish the results given in this paper and Dr. D. K. Crampton for his many helpful suggestions.

# The Use of Charcoal in the Nonferrous Foundry

By R. J. Keeley*, Philadelphia, Pa.

**Abstract**

*The author cites a number of instances in which charcoal was used in the manufacture of nonferrous castings both in the furnace and in the ladle. He shows that, although charcoal has many advantages, it also has disadvantages and whether or not it should be used and where, depends on the type of melting unit and the furnace atmosphere. At the end of the paper, he recommends various practices for different types of furnaces.*

1. In the melting of non-ferrous metals, charcoal perhaps enjoys the distinction of being the oldest and most popular melting adjunct in general use in the brass foundry and is no doubt employed to a greater extent than most of the so-called fluxes and deoxidizing agents.

2. It is also apparent that many foundrymen use charcoal more from custom than from any actual knowledge of the function that it performs.

3. Numerous articles have been written on the subject of various fluxes and deoxidizers for brass melting, but few of these papers have included charcoal under that classification. Probably this is due to the fact that charcoal is looked upon mainly as a preventative of oxidization in the melting process. Aside from the fact that it does prevent oxidization, it apparently is not recognized by many that charcoal has other beneficial uses; also, if improperly used, can produce undesirable results, upon which subject very little information is available.

4. It is believed that some of the difficulties encountered in the production of castings, which were attributed to other causes, were in reality due to the improper use of charcoal.

5. Having in mind that considerable research work is being done on the investigation of various foundry problems of this

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Note: This is one of the papers presented at the Symposium on Deoxidation and Degasification of Nonferrous Casting Alloys held at the 1934 Convention of the A. F. A.

nature, it is the purpose of this paper to contribute a few experiences which will show that the effect of charcoal can be beneficial or detrimental depending upon the manner in which it is used.

## CHARCOAL DEOXIDIZES METAL

6. (A). An example of the proper use of charcoal may be clearly shown by consideration of the following foundry problem and its solution. In a large jobbing foundry producing a miscellaneous line of brass castings, including yellow brass ship fittings, large red brass valve bodies and bronze bearings, it was decided by the management that their foundry practice was at fault because of excessive melting losses and high percentage of defectives. Therefore, an investigation was requested with the view of eliminating these difficulties. Their melting equipment consisted of natural-draft, crucible, pit-furnaces and specification ingot metal was purchased for the various metal requirements. On conducting a thorough investigation of their foundry practice, which included melting methods, metal losses, methods of inspection and testing, it was discovered that they were very indifferent in regard to the use of charcoal and did not attach much importance to its value, as in many instances it was omitted entirely from the heats.

## FLUIDITY INCREASED

7. When forcibly brought to their attention and the various advantages were explained to them, it was agreed that several heats of metal be melted, with and without the addition of charcoal, for comparative purposes.. These heats consisted of all ingot metal. The ingot composition was 85 per cent copper, 5 per cent lead, 5 per cent tin and 5 per cent zinc. At the conclusion of the tests, it was found that melting losses were lowered from an average of 4 per cent to about 2 per cent, also the percentage of defectives due to leakers was considerably reduced. It also was observed that the addition of charcoal rendered the metal more fluid, whereas without charcoal it had a tendency to be sluggish. It is obvious that the practice followed in this foundry resulted in oxidization of the metal during melting and this was overcome by the addition of charcoal to the crucibles before charging the metal.

### USED TO GAS METAL PURPOSELY

8. (B). While most foundrymen are very careful to prevent gases from being absorbed by the molten metal, the following unusual procedure was employed to intentionally gas the metal with the aid of charcoal.

9. In the production of the so-called 80-10-10 phosphor bronze ingot containing approximately 0.75 per cent phosphorus, it was desired by the customer that a metal containing reducing gases be supplied. The purpose of this gassed metal was to counteract the oxidizing effect of open flame furnaces, which were used by the customer in the subsequent production of castings from the ingot. In the production of this ingot, the furnace practice consisted of melting in large, forced draft, coke fired tilting crucible furnaces, pouring the metal into large bull ladles and then into the ingot molds.

10. After some experimenting, it was found that the simplest method for obtaining this gassed condition of the metal, was to place charcoal on the bottom of the empty bull ladles and pour the metal from the melting crucible onto it and then cast the metal into ingot molds. The carbon gases thus generated by the charcoal were absorbed by the molten metal, as was evidenced by the pronounced swelling of the surfaces of the ingots. This swollen condition was caused by the liberation of the dissolved gases upon solidification of the metal. Oxide free metal, that is, metal which has been treated with phosphorus, has been found extremely susceptible to gassing by this method of using charcoal; naturally, since the reducing gases thus generated are not required for deoxidization, a maximum gasification of the metal results. This will explain the pronounced gassing of the metal in this instance.

### FRACTURE REVEALED POROUS STRUCTURE

11. An examination of the fracture of such ingot revealed a very porous structure characteristic of gassed metal. As previously explained, this condition was neutralized by the oxidizing atmosphere prevailing in the open flame furnaces used by the customer in the production of sand castings. Therefore, it is quite evident that if attempts were made to produce castings from such ingot in furnaces operating with either neutral or reducing atmospheres, porous castings would result.

### EXAMPLE OF IMPROPER USE

12. (C). An example of the improper use of charcoal may be shown by the following experience:

13. For the production of manganese bronze castings, a formula to give the desired physical properties was first developed in coke fired pit furnaces, pouring sand-cast test bars direct from the melting crucible. When this formula was put into actual production, the metal was melted in large heats in electric induction furnaces, pouring from the furnace into small ladles and thence into the sand molds. A sand-cast test bar was poured from the first ladle from each heat, principally for fracture test. If the fracture of this test bar was satisfactory, the entire heat was used for the production of good castings, otherwise, the entire heat was rejected and poured into ingot molds.

14. Although satisfactory test bars were originally obtained from metal melted in pit furnaces, the first heats poured from the electric induction furnace gave unsatisfactory test bars. A chemical analysis of these unsatisfactory test bars was made and found to be identical with the satisfactory test bars poured from the metal originally developed in the pit furnaces. Further investigation showed that it was customary to place charcoal on the bottom of the small ladles used in conveying the metal from the electric furnace. As a conclusive experiment, two ladles were poured from the same heat of metal melted in the electric furnace, one ladle being poured without charcoal and the other with the customary charcoal addition. The metal from the ladle poured without charcoal produced a satisfactory test bar, the fracture being identical with test bars cast from the original alloy developed in the pit furnaces. As a result of this experiment, the practice of using charcoal on the bottom of the ladles was discontinued and no further trouble was experienced.

### PRESSURE CASTING FAILED

15. (D.). Another example of the improper use of charcoal may be cited by the following. In this instance, the alloy was red brass.

16. In a foundry engaged in the production of pressure castings from an alloy of 85 per cent copper, 5 per cent lead, 5 per cent tin, 5 per cent zinc, a considerable percentage of castings were found to be defective when subjected to pressure tests.

The melting practice consisted of melting in open-flame, gas-fired tilting furnaces, pouring into small ladles and thence into the sand molds. On investigation, it was discovered that many of the sprues were swollen. This indicated a gaseous condition of the metal. It was found that the furnace was operated with a slightly reducing flame, also, that it was customary to place charcoal on the bottom of the ladle. On eliminating this latter part of their practice, the difficulty was overcome.

### MELTS IN ELECTRIC FURNACE

17. (E). In another foundry, producing pressure castings from two alloys, namely a red brass of 85-5-5-5 composition and a semi-red brass containing 10 per cent zinc, considerable difficulty was experienced because of leakers. The furnace practice consisted of melting specification ingot metal in a 350-lb. capacity indirect-arc electric furnace, pouring into small ladles and transferring to sand molds.

18. On making a general survey, which included examination of the fractures of the defective castings, molding practice, method of gating, sand conditions and pouring temperatures, the first discovery made was that the trouble was chiefly confined to castings produced from the 85-5-5-5 alloy. As an examination of the fractures of a number of defective castings indicated that the metal was gassed, it was decided to first determine, if possible, at what point in the melting practice this gas absorption took place.

### FURNACE HAS REDUCING ATMOSPHERE

19. Although it is an accepted fact that this type of electric furnace operates with a reducing atmosphere, the fact that the high zinc alloy was productive of less defectives as compared with the low zinc alloy, indicated the advisability of looking elsewhere for the real source of this gas. Further investigation showed that charcoal was being placed on the bottom of the small ladles. On eliminating this practice, good castings resulted and losses due to leakers from both alloys was reduced from approximately 6 per cent to about 2 per cent.

20. The question remaining to be answered was why this difficulty was not so pronounced in the case of the 10 per cent zinc alloy. It was believed that the higher vapor pressure of the 10 per cent zinc alloy over that of the 5 per cent zinc alloy tended

to minimize the absorption of carbon gases from the furnace atmosphere and the continued vaporization of the zinc during the transfer to the ladles minimized the absorption of reducing gases generated by the charcoal.

21. From our experience, we have definitely concluded that the many advantages of charcoal are only obtained when due consideration is given to all phases of the melting practice. As a summary, we will outline what, in our opinion, represents the best practice to follow in the use of charcoal with the different types of melting equipment.

### RECOMMENDED PRACTICE

22. *Natural-draft pit furnaces:* Charcoal should be placed on the bottom of the crucible before charging the metal, being sure that at all times the surface of the molten metal is covered. After the metal is melted and raised to the desired temperature, the crucible is removed from the furnace. Before skimming, the entire inner surface of the crucible should be scraped lightly, preferably with a flat skimmer, for the purpose of releasing small particles of charcoal that may adhere to the crucible below the surface of the molten metal. The metal then should be thoroughly stirred by a whirling motion of the skimmer, causing the charcoal and dross accumulated during melting to rise rapidly to the surface, after which a most complete skimming will be effected. This method of stirring will also tend to liberate gases absorbed by the metal during the melting period.

23. *Open-flame furnaces (oil fired):* In general, this type of furnace operates with an oxidizing flame. Therefore, charcoal should be placed on the bottom of the ladles used to transfer the metal to the molds. The reducing action of the gases generated in the ladle by the charcoal thus will neutralize the oxidizing effect of the furnace atmosphere. In this case, the charcoal deoxidizes the metal.

24. *Open-flame furnaces (gas fired):* This type of furnace can be run with either a reducing or an oxidizing flame. When operated with an oxidizing flame, charcoal should be used in the ladles to neutralize the oxidizing effect of the furnace atmosphere.

25. *Electric induction furnaces:* In this type of furnace, charcoal should be charged into the furnace with the metal where it acts simply as a covering to prevent oxidization of the molten

surface of the metal. This procedure thus assures neutral metal and, therefore, charcoal should not be placed on the bottom of the pouring ladles, otherwise, gassed metal may result.

26. *Electric arc furnaces:* This type of furnace has a definite reducing atmosphere. Therefore, charcoal should not be used either in the furnace or in the pouring ladle as this may result in gassed metal.

## CONCLUSIONS

From the foregoing experiences, it is quite evident that

(A)—charcoal can perform three definite and distinct functions, namely, (1), prevent oxidization of the metal; (2), deoxidize the metal; or (3), gas the metal.

(B)—The method of using charcoal and the results desired are dependent upon the atmospheric conditions of the furnace.

# Discussion—Symposium on Deoxidation and Degasification of Nonferrous Casting Alloys

*The papers presented at this, the second Symposium on the Deoxidation and Degasification of Nonferrous Casting Alloys, the discussion of which follows, are:*

*Introduction and General Principles, by C. H. Lorig, Battelle Memorial Institute, Columbus, O., pages 152 to 159, inclusive.*

*Red Brass and Bronze—A Committee Report, pages 160 to 172, inclusive.*

*Yellow Brass Casting Alloys, by L. A. Ward, Chase Brass & Copper Co., Waterbury, Conn., pages 173 to 183, inclusive.*

*The Use of Charcoal in the Nonferrous Foundry, by R. J. Keeley, Ajax Metal Co., Philadelphia, pages 184 to 190, inclusive.*

*In discussing "Aluminum and Its Alloys" for the symposium, H. J. Rowe, Aluminum Co. of America, Cleveland, O., did not present a paper but utilized some of the data contained in a paper presented at the 1932 Convention. This paper, entitled, "Practical Foundry Considerations for Improving the Soundness of Aluminum-Alloy Castings," by Mr. Rowe and E. M. Gingerich, will be found in vol. 40, p. 527 of the* TRANSACTIONS *(1932). For a clearer understanding of comments on Mr. Rowe's remarks, please refer to this paper.*

*The first symposium on this subject appears in* TRANSACTIONS, *vol. 41, (1933), pp. 347-384.*

O. W. ELLIS,[1] *(Submitted in Written Form)*: Dr. Lorig has presented the general principles of deoxidation and degasification of nonferrous casting alloys in a most interesting way. In only one thing am I unable to follow him, and that is in regard to his statement in paragraph 19 of his paper which states that: "Serious gas cavities" in copper "occur only when the oxygen content of the metal falls below a certain quantity." Anyone who has had experience in the production of copper castings, will find it difficult to subscribe to this statement. A useful test in this connection is the pouring (prior to the pouring of a batch of castings) of small test castings into sand, these test castings being about 3 ins. high and about 1½ ins. in diameter. To the ladle of copper, a definite quantity of deoxidizer is added, and then a small test casting is poured. It rarely happens that this casting proves sound, the metal cauliflowering as it freezes because of the evolution of gas.

A further addition of deoxidizer to the ladle will be followed by the pouring of a second test casting. Quite frequently *this* casting will be

[1] Ontario Research Foundation, Toronto, Can.

porous, though it sometimes happens that the amount of deoxidizer that has been added is sufficient to prevent the formation of gas during the freezing of the second test casting. However, I have seen cases where porous test castings have been obtained though three times the normal amount of deoxidizer (in this case cupro-silicon) had been added. It is true, in general, that Dr. Lorig's remarks could be applied to copper-refining practice, but they can scarcely be applied to the practice covered by the title of his paper, which is presumed to deal with nonferrous casting alloys.

It is somewhat interesting that in dictating the above remarks I found it difficult to avoid using the word "gas," and I am wondering whether it is altogether satisfactory to follow the recommendation of the recently appointed committee of the Iron and Steel Division of the A.I.M.M.E. that the term "non-metallic elements" be used in place of the word "gases" in view of the fact that certain important gases, with which we are acquainted in nonferrous metallurgy, are "non-metallic compounds." There is no doubt, for example, that the gas responsible for the porosity of test castings of copper is largely steam.

Dr. Lorig has referred to the fundamental principle known as the Distribution Law, which expresses the ratio between the concentration of a given gas in the metal and its concentration in the surrounding atmosphere. It is generally assumed that this law can be applied without change to metallurgical practice, but there are reasons for questioning the validity of this assumption. So long ago as the spring of 1927, the writer brought to the attention of and discussed with Dr. Rashevsky the question of the distribution of pressure and concentration in a non-uniformly heated gas, and Dr. Rashevsky showed quite clearly that in some cases, when the gas and the metal differed considerably in temperature, the pressure of the gas at the surface of the metal could be twice that at a point remote from the surface.

In view of the fact that all determinations of the solubility of gases in metals and alloys have been carried out in apparatus which has been designed to keep the metal and a large body of gas at one and the same temperature throughout the experiment, it is open to question whether the results can be very strictly applied to cases where the metal varies quite considerably in temperature from point to point of its surface (as, for example, in the arc furnace), and where the gases above the metal, or flux, vary quite considerably in temperature and in composition from point to point.

DR. LORIG: I agree with Mr. Ellis thoroughly on practically every point that he has brought up. In regard to this term "non-metallic elements", I find it very difficult to use, although I do feel that there are difficulties in using the term "gases," too.

E. M. WISE[2]: Mr. Keeley brought up a number of interesting points regarding the use of charcoal. Charcoal consists largely of carbon but does contain considerable hydrogen. Charcoal is very porous and picks up moisture from the air very readily which, upon heating, will probably react with carbon, producing hydrogen and, perhaps, methane.

[2] International Nickel Co. Inc., Bayonne, N. J.

By and large, the effect of fresh carbon is to introduce a little hydrogen, which may raise considerable devilment or may not, depending on circumstances. The resulting effect of hydrogen so introduced, will depend upon the amount of oxygen in the melt and upon the solubility of hydrogen and water vapor in the liquid and solid metal. It will, in consequence, be different for different alloys and melting procedures.

It has been our experience that when charcoal is used, it is best to add it early in the melting operation. By this procedure, we eliminate most of the water and probably most of the hydrogen from the charcoal while the charge is solid and then simply get a reducing effect from CO, which is not so bad. Hydrogen is a bad actor.

MR. ELLIS: I should like to support what Mr. Wise has said in regard to carbon-monoxide. He is correct in suggesting that CO is not a bad actor. His remarks in regard to hydrogen and water vapor are very important.

Before any definite conclusions can be made in regard to the use of charcoal, the exact composition of the charcoal should be known. By that I mean, its moisture content, which has been mentioned by Mr. Wise and its carbon content.

Mr. Wise has indicated that charcoal with quite a considerable degree of moisture can be used, but, assuming that what generally would be referred to as dry charcoal was employed, there would yet remain quite a considerable amount of moisture in the charcoal and quite a considerable amount of gas. Assuming, however, that the results described are absolutely correct. I should like to know exactly what the nature of the charcoal was in each of the individual experiments.

The results of the experiments seem to fall in line with the general ideas that were outlined in the Committee report.* Nevertheless, it might be quite worth-while if something were done to carry these experiments a little further with some knowledge as to the nature of the charcoal indicated.

O. W. ELLIS, (*Submitted in Written Form*): Mr. Ward has referred to the work which I carried out on oxides in brass and has pointed out that zinc oxide does not dissolve readily in brass and that, if present, it will in the main be mechanically entrapped. This is without question true, since a large proportion of the zinc oxide which falls into the bath (in the manner described in paragraphs 6 and 7 of Mr. Ward's paper) rises to the surface and is entrapped in the slag and skimmed from the bath before pouring of the metal from the furnace is attempted. By the words "does not dissolve readily," we understand "does not dissolve in large amounts," but that zinc oxide does dissolve in molten brass has been definitely proved. The fact that the zinc oxide particles in chill castings are smaller and more numerous than are those in sand castings is evidence of this fact.

I am interested in the statement made in paragraph 16 to the effect that aluminum is useful as an aid in getting sharp impressions in castings where there are no pressure requirements. Most foundrymen, with whom I talk, speak of aluminum as causing a skin to form on the molten

* Pages 160 to 172, inclusive.

metal, which tends to increase, rather than to reduce, the castability of the alloy. Possibly Mr. Ward could give some information regarding the quantities of aluminum required to produce the desired sharpness of impression.

The figures quoted in Table 1 are of considerable interest—particularly as showing the deleterious effect of tin on the ductility and resistance to impact of yellow brass. This reduction in toughness is due to the presence of the delta-constituent. Very little less tin than 2 per cent would have failed to cause trouble. The work of Hudson and Jones is worthy to be borne in mind by all engaged in the manufacture of brass, since they were the first to show the limits of solubility of tin in brass at room temperature.

SAM TOUR[2]: This paper by Mr. Ward is to some extent contradictory of parts of the paper by Dr. Lorig. Dr. Lorig arrives at the conclusion that it might be well to use neutral or slightly oxidizing conditions, and Mr. Ward says it is desirable to use neutral or slightly reducing conditions—diametrically opposed.

Paragraph 8 states that tin is usually added after the zinc and, therefore, will not tend to be oxidized. That has been the procedure recommended to foundrymen for many years, that tin be added after zinc; nevertheless, the fact remains that many, many founders still add their tin to their copper before they add the zinc. In some cases, therefore, Mr. Ward's statement will not hold true.

On the subject of aluminum, in paragraph 11, it is stated that aluminum oxide particles float around as a result of deoxidation of brass with aluminum, and macrographs are shown to prove it. In paragraph 15, however, it is stated "with the amount of zinc present it is impossible to have any copper oxide present, and none of the common deoxidizing agents would reduce the oxides of zinc, lead, and tin that would be present." If the statement in paragraph 15 is true, then how is the aluminum oxide in paragraph 11 developed?

Paragraph 21, refers to "slag" and I should like to have the author advise as to what the slag is made up of. This is not very clear in the paragraph.

In the subject of gas solubility, the paper states that hydrogen may be derived from cathode copper which contains large volumes of it. While it might be true that cathode copper contains large volumes of hydrogen, is it true that when you heat that up for melting, you introduce any hydrogen in the molten copper? Isn't it possible that the hydrogen is practically entirely driven off before the copper is melted? Is not the amount of residual hydrogen controlled by the method of and speed of melting?

It seems to me that in general this thought that gases are more soluble, that is, that metals absorb more gases at higher temperatures, might be in error. In other words, we often say that metal picks up more gas at the higher temperatures. Isn't it possible that the actual solubility of gas in the molten metal decreases with increasing temperature, but, due to the higher temperature, the rate of solution is greater so that

[2] Lucius Pitkin Inc., New York.

equilibrium concentration of gas in the molten metal is more nearly reached?

It is entirely possible, in my mind, that the solubility of a gas would be less at 2300 than at 2000 degrees Fahr., but, holding the metal for five minutes at 2300 degrees Fahr., it might absorb much more hydrogen than for fifteen minutes at 2000 degrees Fahr., simply because these reactions might take place much faster at the high temperature.

If the question of time is the important thing on gas solubility, we should stress the necessity of quick melting instead of slow melting. Melt hot but melt quickly; do not hold it at that high temperature a long time but pour it quickly to avoid gas absorption. Of course, that is a debatable question, but I should like to hear some comment from Mr. Ellis on that question.

MR. ELLIS: The work of both Japanese and German investigators has indicated quite clearly that the solubility of hydrogen increases as the temperature rises.

Another important point is that the solubility of hydrogen in solid copper increases with the temperature. This phenomenon is not a characteristic of copper alone. Therefore, there is no reason to suppose that because cathode copper is heated to the melting point, one will get rid of all the hydrogen. The higher the temperature, the greater is the solubility.

It is difficult to talk in terms of conditions that are not equilibrium conditions, but we have to keep in mind what equilibrium conditions are when we are discussing these reactions.

CHAIRMAN LORIG: Theoretically, at least, the heat of solution determines, to some degree, whether a liquid will or will not absorb more gas which increasing temperatures. As little is known about heats of solution of different gases in molten metals, the question of whether or not greater quantities of gas are absorbed at higher temperatures will be debatable for some time to come.

J. G. G. FROST[4]: Mr. Rowe has pointed out the difference between pinholes caused by gases and those caused by shrinkage. In many cases, the distinction is even more marked than his slides indicate.

Our research department has been called to the help of aluminum foundries for many years, when they were having troubles. Many of these troubles were in the form of pinholes and we were forced to make a classification such as Mr. Rowe shows. It is an excellent aid in diagnosing the trouble. The surprising thing is, how few times there really are gases in aluminum during regular foundry production.

I should like to describe a few practical experiences with pinholes and the pickup of gases in aluminum.

One firm held No. 12 aluminum alloy in an open-hearth furnace, in contact with a direct, natural gas, reducing flame for 48 hours at between 1500 and 1520 degrees Fahr., at the end of which time, castings of excellent in quality and free from pinholes or other signs of gassed metal, were made in a permanent mold at the regular production rate.

During a test, a 4 per cent copper-aluminum alloy was held in an

[4] National Smelting Co., Cleveland, O.

open-hearth furnace in direct contact with a natural gas flame (oxidizing most of the time) for a period of 75 hours. The temperature varied between 1300 and 1450 degrees Fahr. during the entire time. Then test bars were cast and found to have the same tensile strength and elongation as had the bars cast 75 hours earlier. There were no pinholes or other signs of gas absorption.

All sorts of aluminum alloys are being melted in direct contact with natural gas, artificial gas and oil flames without any gas pickup that can be detected in the castings produced. Many of these fuels contain considerable moisture, so that it is not reasonable to suppose that aluminum picks up gases readily. Over 90 per cent of the pinhole troubles that we have serviced over the years, have been caused by shrinkage due to the methods of gating, pouring, etc.

When aluminum really has absorbed gas, which is causing pinhole difficulties, some of this gas may be seen rising from the top of the sprue just as it is freezing. It resembles a slight effervescence.

In one foundry, they were introducing gas into the metal just before casting by pouring it with a drop of 4 feet into the ladle. A handful of flux, which contained 10 parts of water of crystallization in its formula, was placed in the bottom of the ladle. These castings really had spherical pinholes which showed up during the polishing.

Another foundry, which was producing a casting which must be absolutely free from defects, was having trouble with a few very fine scattered pinholes near the sprue. These were permanent mold castings and a little gas could be seen to rise from the sprue just as it was about to set. They were using artificial gas, said to contain about 40 per cent free hydrogen in an open flame furnace. The trouble was finally traced, not to the hydrogen, but to damp somewhat corroded ingots which had been stored out in the open. When these ingots were slipped into the bath of metal a vigorous bubbling action set up for a short time. Though the ingots were warmed there was still sufficient hydrated alumina to carry mosture into the melt. The use of fresh ingots cleared up the trouble. Damp corroded castings will do the same thing.

There are two proven ways to cause molten aluminum to absorb gases. One is to bubble gases through the metal by churning it or otherwise. The other is to introduce water (moisture) below the surface in the form of crystallized salts, corroded metal (hydrates), wood or similar devices. The molten metal appears to break up the water and absorb a portion of the hydrogen thus formed.

Gas does not seem to be able to penetrate the surface film of a bath of aluminum from above at atmospheric pressures, at least this does not occur below 1500 degrees Fahr. whether there is moisture in the fuel or not.

The foundryman who treats his aluminum with ordinary respect does not have absorbed gases.

A. M. ONDREYCO[5]: In paragraph 36 of Mr. Ward's paper it says: "In conclusion, this paper may be summarized by saying that with care in melting and casting, no deoxidizing agent is necessary." As far as our

[5] Westinghouse Air Brake Co., Wilmerding, Pa.

experience on red brass is concerned, this is true, and I want to support Mr. Ward's statement in that respect, but the next statement, we cannot subscribe to. That is: "And the best method of degasification is to keep the casting temperature as low as possible."

I fail to see how it is possible to get rid of the gas that is absorbed by the metal in the furnace by changing the casting temperature. We have had experience with closed furnaces, charged with turnings wet with oil. The charge consisted of about 30 per cent turnings. Turnings, wet with oil, will generate gas in the furnace, the metal absorbs the gas and very unsound castings result.

As to using deoxidizing agents, we feel that it is not necessary, and we make pressure castings.

L. B. THOMAS[6]: Several years ago, while employed at the Westinghouse Air Brake Co., Wilmerding, Pa., we ran a number of tests in the brass foundry to determine the effect of deoxidizers when added to our several alloys.

At that time, we were melting our high zinc alloys in 18-42-in., oil-fired, Schwartz furnaces. Our zinc content ran between 18 and 21 per cent. Nearly everyone present will agree that we had sufficient zinc content present in our alloy to act as a deoxidizer. However, although we were using very little new metal, possibly 4 per cent, and the charge consisted of returned scrap, gates and composition ingot, our casting losses gradually increased with machining difficulties. A careful examination and investigation of our defective castings revealed that they were contaminated with very small white particles that resembled zinc in appearance but were found to be cassiterite or tin oxide. Small amounts of phosphor-copper and the so-called "Boronic" copper failed to eliminate this condition or to help machinability.

Under the circumstances, it seemed foolish to use deoxidizers with this high zinc alloy. The management agreed to permit us to use considerably less zinc in our common brass mixture and, after confirming our theories by actual test, we set a standard of 20 per cent new metal addition to each 650-lb. furnace charge.

It was necessary, at times, to add considerable zinc to our Schwartz furnace charge. The greater part of the zinc was added first when charging the furnace and covered with 100 lbs. of turnings, which contained a flux consisting of 2 parts lime and one part fluorspar. The composition ingots and copper then were added and lastly the gates, sprues and defective castings. When the heat was nearly ready to pour, the remaining zinc was added and the whole bath stirred thoroughly; then the tin and lead were added and the bath was agitated strongly again before starting the casting operation.

With this new alloy having about 10 per cent zinc, we did add a copper-nickel-tin-phosphor alloy in very small amounts which gave beneficial results.

Regarding furnace atmosphere, speaking of the 42-in. Schwartz furnace, at that time, we were trying to maintain a neutral or slightly reducing atmosphere which was saving us metal and making for a lower

[6] Ohio Brass Co., Mansfield, O.

melting loss, but probably through reduction, contaminated the metal with the various combinations of gases and metals.

MR. WARD: Mr. Ellis has referred to the percentage of aluminum which is used to get sharper impressions. We have found in many instances, where we are casting small intricate shapes or ornamental castings, where there are a number on a gate, that 0.10 per cent of aluminum is quite often useful.

Mr. Ellis also spoke of the 2 per cent tin having a deleterious action due to the delta-constituent being present. We recognize that fact and this particular set of tables was taken from a study where we were attempting to cut down on the number of alloys in use in our foundry and to find out which were the best and what percentages of the various elements we ought to use. This particular alloy is one that was used and we found that it was a very poor alloy for the purpose.

Mr. Tour's remarks as to the proper condition of furnace atmosphere are well brought out and it is true that Dr. Lorig and the author are, apparently, in disagreement on this point.

The point that should be emphasized is that both papers recommend a neutral atmosphere as the ideal condition. Whether any variation from this should be on the oxidizing or the reducing side, is certainly open to question and, in my opinion, there is still much work to be done along these lines before we can definitely say just what conditions are best.

As to the remarks that Mr. Tour made relative to paragraph 8, tin may be added before the zinc, and it is often done in that manner, in which case stannic oxide will be formed due to the oxidation of the tin.

As to adding aluminum to a brass of this type, one notices the violent reaction, especially if the aluminum is not immersed quickly and oxide is formed at the surface of the bath. The minute aluminum starts heating, aluminum oxide is formed and we know that it is present in castings of this type when added last.

As to the kind of slag to which I referred, I did not feel that there was any place in this paper for a discussion of the various types of slag. There are a number of slags varying from an ordinary glass up to and through all the various commercial slags which are on the market and the choice of a proper slag will depend entirely on the nature of the impurities present.

The other two questions that Mr. Tour brought up as to the solubility of hydrogen in copper and the hydrogen being derived from the cathode copper, have been answered by Mr. Ellis.

Regarding Mr. Ondreyco's remarks on degasification by keeping the temperature low and on the effect of turnings, it is a well-recognized fact that you can get large volumes of gas from oily turnings. Therefore, degasification could not be expected by keeping the temperature low when such large volumes of gas are present.

# Flowability of Molding Sand

By H. W. Dietert* and F. Valtier*, Detroit.

**Abstract**

*Flowability is defined in this paper as the property which enables sand to flow when a ramming energy is applied. The greater the ease of flowing, the more readily will the sand form a continuous and uniform mold surface. The authors describe a test for flowability, which consists of measuring the movement of sand grains after an initial ramming. The relation of flowability to the other properties of sand is summarized as follows: It is increased by a decrease in moisture in clay content, in green sand strength, in green permeability, or an increase in grain fineness towards the finer grain materials. Flowability is deceased by the addition of sea coal to molding sand.*

1. The flowability of molding sand enters into the production of every sand mold produced in a foundry. A method of testing the flowability of molding sand and the relation that it bears to other sand properties is presented in this paper.

2. Molding sand possesses, to a varying degree, a property which enables it to flow when a ramming energy is applied. The greater the ease of flowing, the more readily will the various sand grains, comprising a mold, flow together until all sand grains are in contact, thus forming a continuous and a uniform mold surface.

3. A photographic representation of this sand property is illustrated in Fig. 1. The sand specimen *B* is representative of a molding sand possessing a very low flowability of 56, while the specimen *A* represents a sand with a high flowability of 90. The low flowability molding sand *B* has void spaces on its surface which would cause weakness in the strength of the mold and roughness of casting surface. The high flowability molding sand *A* has a continuous uniform surface and is capable of producing a smooth casting surface.

* Harry W. Dietert Co.

Note: This paper was presented at the session on sand control and research at the 1934 Convention of the A. F. A.

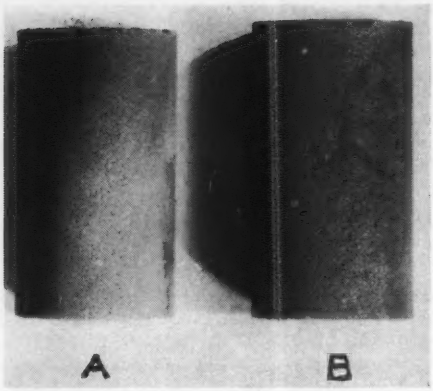



FIG. 1—TWO SPECIMENS DEMONSTRATING THE DIFFERENCE IN FLOWABILITY OF FOUNDRY SANDS. THE SPECIMEN ON THE LEFT HAS A HIGH FLOWABILITY AND THE ONE ON THE RIGHT, LOW FLOWABILITY.

4. The grain structure of these two sands is identical and they differ only in the type and quantity of bond. The specimens shown in Fig. 1 are 1⅛ in. in diameter and 2 in. in length. They were double end rammed which explains the appearance of the low flowability void spaces near the center of the specimen *B*.

## PRACTICAL USE

5. The flowability of molding sand has a very practical application in the foundry. It explains certain behaviors of molding sands, and provides a means of improving casting quality and of reducing the time of ramming the mold.

6. High flowability will improve the smoothness of the casting surface, while low flowability will contribute materially to a rough casting surface finish. One needs only to refer to the surface of sands *A* and *B* in Fig. 1 to visualize the effect that flowability has on the surface finish of castings. Metal penetration into the mold is increased as flowability decreases.

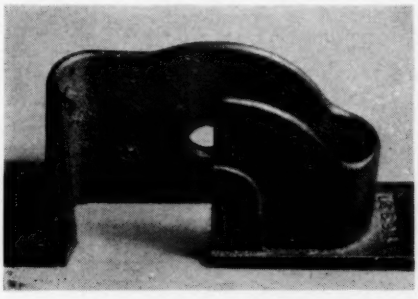
7. A molding sand may be prepared that has such a low flowability value that the molding machines available in a foundry will not properly ram a mold. A condition of this kind will occur when the green strength is very high and the sand becomes stiff or low in flowability, in which condition molding machines will not ram the mold satisfactorily.

8. Patterns may have pockets or restricted sections which

will tax the flowability of a sand. A casting produced from such a pattern design is shown in Fig. 2. The surface inside the casting is produced in green sand and the roughness or projections on the surface was caused by a low flowability of the molding sand.

9. The speed with which a mold may be produced is influenced markedly by the flowability of the sand. A low flowability sand will require a larger number of jolts or greater air pressure on the squeeze operation.

10. The items enumerated all enter into the cost of castings which makes it possible to reduce cost by increasing flowability.



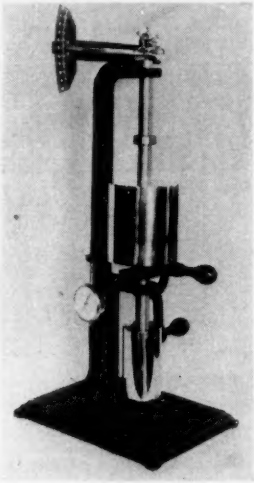


FIG. 2—(ABOVE) CASTING SHOWING A DEFECT CAUSED BY LOW FLOWABILITY. FIG. 3—(RIGHT) APPARATUS FOR TESTING FLOWABILITY OF MOLDING SANDS.

11. The flowability of molding sand may be determined by measuring the movement of sand grains for a given ramming force after an initial ramming. A sand with a high flowability will show very little movement of the sand grains after an initial ramming, because the initial ramming is sufficient to bring the sand grains together. A low flowability sand will show a high movement of sand grains after the initial ramming because the initial ramming is not sufficient to bring the sand grains together.

12. The movement of the sand grains or flowability can be determined best by measuring the decrease in length of sand specimen made with the standard A.F.A. sand rammer equipped with a flowability indicator dial. The measurement is made between the fourth and fifth drop of the ramming weight. Most consistent results are obtained between the fourth and fifth drops, because

most of the variables, such as uneven filling of sand into the specimen tube, are overcome.

13. A flowability dial indicator attached to the sand rammer is shown in Fig. 3. This indicator measures the change in sand specimen length between the fourth and fifth ramming blow in 0.001 of an inch. A sand showing zero movement has 100 per cent flowability while one showing 0.050 in. movement possess 50 per cent flowability. The flowability indicator (Fig. 3) is graduated to read directly in percentage of flowability and not in inches of sand movement.

14. The procedure followed in the flowability test is outlined below:

(1) Weigh out sufficient sand to give an A.F.A. sand specimen 2 in. long with 3 blows of ramming weight.
(2) Ram the sand specimen with a total of 4 blows.
(3) Set the bezel of the flowability indicator to read zero.
(4) Ram the fifth blow.
(5) Record reading of flowability indicator as percentage flowability.

15. That procedure is followed in the foundry for flowability control testing. The flowability of new molding sands is determined by reducing the green compression strength of the new sand to 5 lbs. at temper moisture content. Sand grains as secured from the fineness test of the new sand are mixed with the new sand to bring the strength to 5 lbs. In this manner, all new sands are tested under like strength conditions, which is essential.

## FLOWABILITY AS RELATED TO OTHER SAND PROPERTIES

16. The various physical properties of a sand such as fineness, moisture content, permeability, strength, clay content and others are quite closely interrelated. A change in one will alter the other properties and many of these relations have been expressed in exact formulae. The relation that flowability bears with the above mentioned sand properties is of practical value.

### *Flowability versus Moisture*

17. The most variable item in molding sand is moisture and it has a noticeable effect on flowability. The curve *A* in Fig. 4 shows how moisture affects the flowability of a molding sand. At 2.2. per cent moisture the flowability is 85, and at temper (7 per

cent moisture) is 76. When the moisture is increased beyond temper, the flowability increases again.

18. The flowability of a sand is less at temper than at either dry or wet state due to the fact that at temper the clay bond possesses its greatest strength, thus requiring greater ramming force to ram the sand in place.

*Flowability versus Clay Content.*

19. The quantity of clay bond contained in a molding sand will materially influence the flowing property of a sand. The flowability-clay content, curve *B* in Fig. 4, illustrates graphically

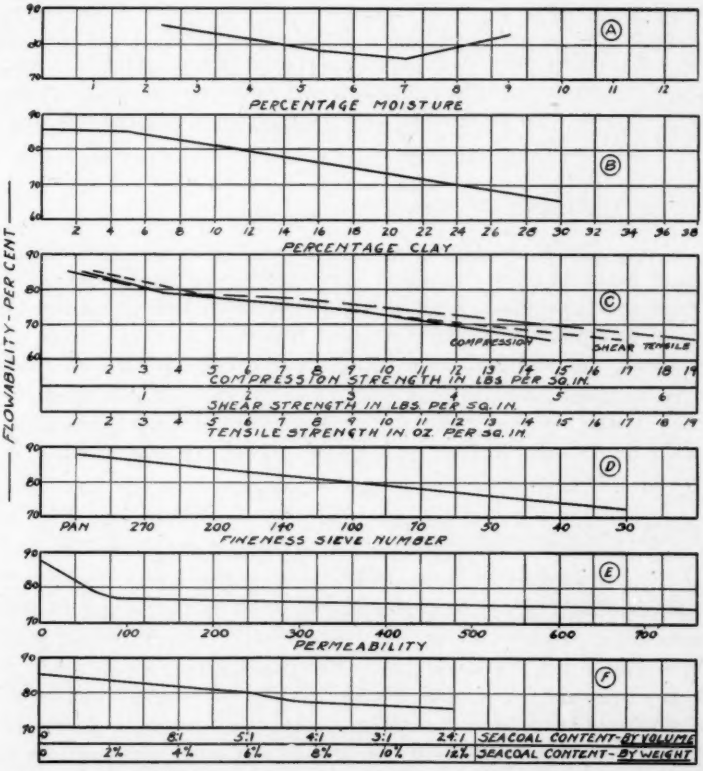



FIG. 4—SERIES OF CHARTS SHOWING THE EFFECT OF DIFFERENT VARIABLES ON THE FLOWABILITY OF MOLDING SANDS. FROM TOP TO BOTTOM—FLOWABILITY AS AFFECTED BY A, MOISTURE CONTENT; B, CLAY CONTENT; C, STRENGTH; D, FINENESS NUMBER; E, PERMEABILITY WITH A COMPRESSION OF 5 LBS. PER SQ. IN.; F, SEA COAL CONTENT.

the decrease of flowability as the clay bond content is increased. The sand without clay and up to 4 per cent has a flowability of 86 and then decreases to 66 at 30 per cent clay. The curve *B* is representative for a synthetic sand made of Michigan City sharp sand and a fire clay bond. The plasticity of the clay will have an influence on the flowability of a sand. The lowest flowability obtained to date is 56, secured in a sand bonded with a mixture of two bonding materials.

*Flowability versus Strength.*

20. The strength of a sand influences the flowability in the same manner as clay content. This is shown in curves *C*, Fig 4. The greater the clay content the greater the strength, with the result that flowability decreases as either increase. High tensile, shear or compression strength are not inducive to good casting finish, partly due to the fact that flowability is reduced, causing swells and metal penetration.

*Flowability versus Fineness.*

21. The grain structure or fineness of a molding sand has much to do with the flowability. The coarser the sand grains, the lower the flowability. In Fig. 4, curve *D* shows that pan material has a flowability of 88 while 30 mesh material has a flowability of 72, when the sand grains are bonded with a fire clay bond to yield a compression strength of 5 lbs. This is a most definite example that flowability and mold hardness are two distinct properties. Mold hardness is highest with coarse grains, while flowability is lowest under similar conditions.

*Flowability versus Permeability.*

22. The relation between flowability and grain fineness is a straight line. Since the permeability varies as the square of the fineness, it follows that the relation between flowability and permeability is not a straight line. The relation between flowability and permeability is shown in curve *E*, Fig. 4. The flowability of a synthetic sand bonded to 5 lbs. compression strength decreases rapidly up to a permeability of 75. This would correspond to a fineness range from pan to 70 mesh, which covers substantially two thirds of the length of curve *D*. In curve *E*, this range covers substantially one tenth of the curve length, consequently, the flow-

ability change is localized in a small part of the permeability-flowability curve *E*.

23. Nonferrous and gray iron foundrymen will experience a decrease of flowability when the permeability of the sand increases. Steel foundrymen who work their sand above a permeability of 100 will not find much of a change in flowability for a permeability change.

*Flowability versus Sea Coal Content*

24. Sea coal additions to molding sand, when strength is allowed to increase due to increase of sea coal, decrease the flowability, as is illustrated in curve *F*, Fig. 4. The molding sand without sea coal has a flowability of 86 and with a 7 per cent addition of sea coal, which is very practical addition, the flowability decreases to 79. This reduction in flowability is due to an increase of green sand strength and also is due to the fact that coal in itself does not possess a high flowability.

## APPLICATION OF TEST

25. The practical application of flowability testing may be divided into two groups: the flowability of new sands or clay bonds, and the flowability of production sands.

*Selection of New Sands.*

26. Flowability of new sands is determined by diluting the sand as received with sand grains such as wash from a sample of the sand, until the green compression strength is 5 lbs. per square inch. The standard strength is used with all new sands, natural or synthetic, so that all will be compared on an equal strength basis, and sands possessing high strength will not be unduly handicapped. Choosing new sands with the best possible flowability that may be secured under the other specified sand properties will add much to the results obtainable.

*Control of Production Sand Flowability.*

27. Production sand in a foundry will change in flowability as rapidly as in any other property. A change in any one sand property will change the flowability, as is revealed in charts in Fig. 4.

28. Flowability of a production sand may be increased by

decreasing moisture under temper, clay, green strength, permeability, fineness or by increasing the moisture beyond temper or by increasing the fineness.

## CONCLUSIONS

29. The most advantageous method of securing a practical knowledge of flowability of molding sands is to study the influence that each physical sand property has on flowability.

*Moisture*—A moisture decrease under temper point or moisture increase above temper will increase the flowability.

*Clay*—A clay content decrease will increase the flowability.

*Strength*—A green sand strength decrease whether compression, shear or tensile will increase the flowability.

*Grain Size*—A grain fineness increase towards the fine grain materials will increase flowability.

*Permeability*—A green permeability decrease to 100 will increase flowability slowly and below 100 the flowability increase is very rapid.

*Sea Coal*—The addition of sea coal to molding sand decreases the flowability.

30. Flowability is an important sand property and the attention of every foundryman to this characteristic of molding sands will yield immediate progress in the foundry industry.

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## DISCUSSION

DR. H. RIES[1]: There is no doubt that the property of flowability is a very important one, and that we should have a standard test for determining it. The Committee on Standard Tests has, from time to time, considered the question of flowability and has studied various tests that have been suggested for determining it. At the present time, a sub-committee has begun the study of Mr. Dietert's suggested method, but, as the details of it came to the committee's attention only recently, it has not yet had time to complete its studies, and to make a report.

There are one or two questions that I venture to suggest. They are not criticisms. Are we really measuring the flowability of the sand by this test? That is a question which is well worth considering.

[1] Geology Dept., Cornell University, Ithaca, N. Y.

Another point is this: Mr. Dietert determines the flowability by the amount of reduction in volume that takes place between the fourth and the fifth ram. Now, when we ram up a core with our standard rammer for making tests, we give it three rams, and the reason we ram it under the conditions specified in the test, is that we think that dropping the 14-lb. weight from a height of 2 ins., three times, gives us approximately the amount of compaction that we find in the average mold. So, one might raise the point: Should not the flowability of the sand be determined, if possible, at or before the third ram, instead of carrying it on to the fourth and fifth ram.

Another question which might be asked is how certain properties of the sand itself affect the flowability. What effect does the character of the bond clay have? In addition to the texture of the grain, as pointed out by Mr. Dietert, we may ask whether the shape of the grains has an influence. To express it differently, which gives greater flowability, a rounded or angular grain.

Some time ago, when I was trying to get examples of good flowing and poor flowing sands, Mr. Dietert sent me two samples, one of which was of good flowing quality, and the other was supposed to have poor flowing qualities. When I examined them, I found that the sample with the good flowing qualities was composed of very angular grains, while the one of lower flowability was made up of rounded grains. I rather expected that the rounded grains might make the sand move better than the sharp ones.

R. E. APTEKAR[2]: I want to refer briefly to some earlier work on flowability by O. E. J. Abrahamson. He used a hardness tester somewhat different in design and functioning from the instrument designed by Mr. Dietert, and which I found to be very useful. The principle in the action of this instrument was a definite weight ram, with a very sharp point, with a 15-degree cone that penetrated into the sand when the specimen was rammed, or could be applied to the mold. Its reading varied from 24 down to zero in reverse ratio and measured, to a very large extent, the flowability of sand, because it had the wedge that penetrated into the sand, differing radically from the measure of the properties as a distorting influence on the bond, as compared to the compression which the present test under discussion illustrates.

I want to refer to Mr. Dietert's one point on the influence of sea coal in reducing the flowability of sands which contradicts what I told you.

If we were to take the flowability of new sea coal, the angularity of the sea coal, after grinding, does materially reduce the flow. When we take an aerated sand, however, that has been mulled, and used in a heap, I have found on all sizes of the grains, that the presence of sea coal makes possible the reduction of clay in the sand, to produce equivalent strength, and results in a better-flowing sand than could be obtained with lower sea coal values.

H. W. DIETERT: To take up the various subjects as they were brought up, I will take up the number of rams first. We have measured the flowability of the sand specimen from one to ten rams and find that the flowability relation is constant throughout that range of rams. As we

[2] Foundry Consultant, Ypsilanti, Mich.

obtained the most accurate readings if we passed, say three rams, we finally chose the fourth to the fifth to obtain more accurate readings with the least amount of fluctuations.

As to the physical property of the clay the sand is bonded with, we tested a large number of bonding materials to find out how they affected the flowability. The difference in flowability affect of bonding clays is not as great as you might assume it to be.

As to the grain shape, I do not believe that it is of much practical importance, particularly in the East and Midwest. It has some importance in the Far West, for there is a sand that is produced in one of the Rocky Mountain states which is very sharp and of flat-grained material. I know of no other place where the shape of grain structure is of so much importance. In our investigation, we tried to obtain perfectly round sand grains and angular grains, sub-round ones and sub-angular ones, and measure the difference in flowability, and the difference was of no practical importance.

Mold hardness and flowability are two distinct physical properties. Mold hardness may be high and the flowability exceedingly low.

Referring to Mr. Aptekar's comments on effect of sea-coal, all I can say is that these are actual tests that we have presented here and the results will have to speak for themselves.

H. B. HANLEY[3]: Some years ago, I came to recognize the flow in molding sands, and observed the successful working of sands with good flow properties as against sands with poor flow properties. These observations were made in sanitary ware plants making bath tubs, and in foundries engaged in making piston rings in mass production

Molding sands of the finer grades seem to demonstrate that flowing property much more than the coarser sands. The remedy for increasing the flow, in my experience, is through the use of new sand additions and proper tempering.

The instrument Mr. Dietert has devised can at best give only a relative measure of this particular property. The best check on the flow of molding sands comes directly from the molding machine operation. Castings made from a sand with poor flowability will show coarseness on the surface from sand not uniformly rammed.

H. W. DIETERT: It may seem that Mr. Aptekar and I are not in agreement on the effect of sea coal, his idea on sea coal being that the strength of the sand is maintained constant as sea coal was added to the sand. The flowability chart shown in our paper holds true when the strength is allowed to increase by sea-coal addition. Whenever we speak of flowability, we must specify the strength. I think that is where we are at variance in our ideas at the present time, and, if that is the case, I think we agree.

B. C. YEARLEY[4]: Has the author any data on combination of grain sizes? It seems to me that there is a good deal of possibility of a keying action where you have various combinations of grain sizes, and such a keying action would materially reduce flow.

Taking it from the practical side, I remember one unfortunate ex-

[3] American Laundry Machinery Co., Rochester, N. Y.
[4] National Malleable & Steel Casting Co., Chicago, Ill.

perience in which we were trying to make a fairly large casting in a rather fine sand, and we could not make it on a jolt machine because the sand bridged, but with a coarser sand we eliminated that difficulty, so it is rather hard for me to believe that the flowability actually does decrease with increased grain size.

I wonder whether the keying action of varying grades of size is less instead of more.

H. W. DIETERT: The thoughts so ably injected into this meeting really could be answered in another year's work. I might say that the chart *D*, Fig. 4, does show the flowability for fineness of one size at a time. At 270 mesh it was all 270 material at a standard compression strength of five pounds, but what we tried to present here was something to give you an idea of how various grain materials affected flowability.

I believe that we will find that flowability will be affected by grain distribution or interlocking of grains, but it has been found in our foundries and in another Michigan foundry, that fineness and flowability are markedly related.

The permeability-flowability curve as shown in chart *E*, Fig. 4, may vary for different sands. There is no question about that. However, it is representative of many sands. I think it represents an average condition—as average a condition as could be presented in a short paper.

H. B. HANLEY: Regarding paragraph 26, will the author clarify for us the procedure as related to the standard use of 5 lbs. per sq. in.

H. W. DIETERT: This is a very important question and I am truthful to admit that we have much to learn in testing the flowability of new sands.

What we were primarily interested in was to compare flowability of new sands not as they were received, but in an endeavor to compare the flowability of the new sands as they would be used in a foundry. We did not want to handicap high-bonded sands in flowability. The high-bonded sands would always show low flowability because of the large amount of clay substance contained. We do not use them in our foundry as received for molding. They are diluted with heap sand and we want to dilute the new sand down to the strength in which it would be used in the foundry before testing for flowability.

We chose 5 lbs. as being as low a compression as we could possibly use in our foundries, yet being low enough to reach most of the new sands. It would be rather difficult to step up the strength of a new sand and yet not change its flowing properties or its physical properties which would affect flowability.

I grant you that the method of testing flowability for new sand outlined here, presents difficulties, but how else to do it, we did not know at that time nor at the present time. It does give us a practical method of testing the various sands received and for studying the flowability, trying to determine whether a new sand from a different source would give us a better casting finish.

L. H. MARSHALL[5]: It is an interesting fact, the way in which green strengths seem to be in inverse ratio to the flowability; in fact, the data presented show that the compression and tensile strengths are consistently

[5] L. H. Marshall Co., Columbus, O.

in inverse relation to the flowability. In curve *E*, Fig. 4, however, we find that flowability decreases as the permeability increases, without any maximum relationship shown.

In ordinary practice we usually find that there is a maximum in permeability as well as a maximum in strength. I wonder what the explanation is.

H. W. DIETERT: It is true that we never get all the ideal sand properties in our molding sand. We have to choose to obtain a general average of all, and the point as brought up by Mr. Marshall calls attention to the fact that we obtain a low flowability at temper when we get the highest permeability, that is, for that given sand.

Curve *A* really does not have any relation to curve *E*. Curve *A* is for one sand, and curve *E* is for a large group of sands, showing a general relation between flowability and permeability.

# Effect of Copper in Malleable Iron

By C. H. Lorig,* Columbus, O., and C. S. Smith,**
Waterbury, Conn.

**Abstract**

*The authors have experimented with copper-bearing malleable iron, and have found that it has certain advantages over ordinary unalloyed malleable cast iron. They found that copper is easily soluble, either with the charge or in the ladle, and that at least 3 per cent goes into solution. Under 0.50 per cent copper has little effect on the physical properties, but from 0.70 to 1.25 or 1.50 per cent improved the endurance strength. The mechanical properties of iron containing more than 0.70 per cent copper are improved by precipitation-hardening. Copper does not change the fluidity or shrinkage of malleable iron, nor does it increase cracking. It has no marked influence on the structure. Copper accelerates graphitization considerably, both in the first and second stages. It reduces the susceptibility to intergranular embrittlement.*

1. The alloying of copper with malleable cast iron is not new. It frequently occurs as an element not intentionally added, but which enters the iron through its presence in the furnace charge; yet sometimes it purposely may be added, primarily to improve the atmospheric and acid-corrosion resistance of the iron. In either instance, the quantity of copper may be but a few tenths of 1 per cent which, for the most part, adds little to the mechanical or physical properties. It is when the copper content exceeds 0.70 per cent that real and important modifications in properties are noted and the iron is sensibly benefited in tensile and yield strength by the added alloying element.

2. Aside from the improvements to mechanical properties which originate from the presence of copper in malleable cast iron, other benefits accrue from its presence. First, the graphitizing reactions, both in the first and in the second stages of graphitiza-

* Metallurgist, Battelle Memorial Institute.
** Research Metallurgist, American Brass Company.

Note: This paper was presented at a session on Malleable Iron Founding at the 1934 Convention of A. F. A.

tion, are accelerated by copper. This effect, quite analogous to the action on white cast iron of other graphitizing elements such as silicon, aluminum, and nickel, is progressively the stronger the more copper that is contained in the iron. Next, the embrittlement sometimes met in malleable cast iron, or susceptibility to intergranular embrittlement at galvanizing temperatures, is definitely minimized by the presence of copper. Again, of less widespread and immediate application, though perhaps of considerable technical importance is the ability of the copper-bearing malleable iron to be strengthened and hardened through precipitation hardening.

## ALLOYING MALLEABLE IRON WITH COPPER

3. Copper is one of the elements most easily alloyed with iron. It is not oxidized in the melt, therefore none is lost from the metal whether it is contained in the scrap or whether it is added at any period during the process of melting. Its low melting point (1981 deg. Fahr.) makes it a desirable ladle or spout addition. As much as 1.50 per cent copper in the form of shot has been added to small ladles of iron with complete solution, uniform distribution, and without seriously lowering the temperature of the metal.

4. Molten cast iron can take into solution somewhat more than 3 per cent copper. As this quantity usually exceeds the alloying requirement for the iron, no separation of liquid copper on casting nor any marked segregation of copper will normally occur in copper-bearing malleable iron castings.

5. Foundry practice in the manufacture of copper-bearing malleable iron castings does not differ from that for the regular grade of castings. The introduction of copper makes no appreciable change in casting shrinkage, metal fluidity, or tendency for the castings to crack. Some evidence actually suggests reduction in the cracking tendencies; yet, for the most part, no tangible difference in the behavior of the alloyed and the unalloyed iron in foundry practice is shown.

6. As copper is a mild graphitizing element in white cast iron, certain precautions in the selection of the base analysis necessarily must be followed to avoid mottling or flake-graphite formation. This becomes most serious in the cupola grade of iron where, because of its propensity to mottle even in sections of only moderate thickness, the effect of copper on flake-graphite formation is pronounced as shown in Fig. 1.

7. The curves were obtained from observations on the occurrence of mottled areas in various series of step-bar, hard-iron castings poured from two heats of electric furnace iron that resembled cupola iron in composition. Each heat of metal provided

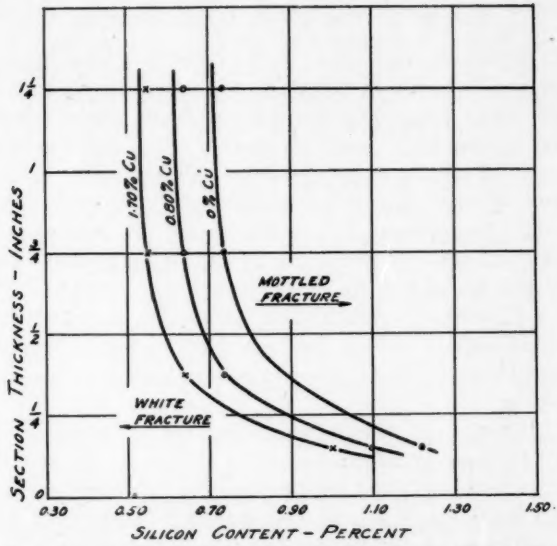


FIG. 1—RELATION OF SECTION SIZE, SILICON CONTENT AND COPPER CONTENT ON FLAKE-GRAPHITE FORMATION IN HARD IRON CASTINGS.

six series of step-bar castings differing from one another mainly in their silicon and copper contents. The heat compositions were as follows:

| Heat | Carbon Per Cent | Silicon Per Cent | Manganese Per Cent | Sulphur Per Cent | Phosphorus Per Cent |
|---|---|---|---|---|---|
| 421 | 2.81 | 0.55 | 0.54 | 0.146 | 0.137 |
| 422 | 2.91 | 1.03 | 0.58 | 0.168 | 0.150 |

8. It is obvious that mottling is assisted by the presence of copper[1] and that for the iron in question each 0.80 to 1.00 per cent of copper has the equivalent effect of 0.10 per cent silicon. This relationship between the silicon and copper contents seems to exist for normal air furnace irons as well.

[1] Some investigators, notably A. L. Boegehold (U. S. Patent 1,707,753, 1929) and C. S. Smith (unpublished data, American Brass Co.) and some work at Battelle Memorial Institute on gray cast irons have shown an increased stabilization of white iron as the result of small quantities of copper, less than 0.50 per cent.

9. The mere fact that flake-graphite formation in white iron is accentuated by copper immediately leads to the supposition that the graphitization rate upon annealing should be accelerated by copper. This reasoning is correct.

## EFFECT OF COPPER ON GRAPHITIZATION

10. Malleable irons made in the laboratory and in plant air furnaces and containing various percentages of copper were annealed at given temperatures until all of the primary cementite had been decomposed. Decomposition of cementite was traced by microscopic examination of specimens removed from the furnace and quenched after various periods of heating or by following the expansion of specimens on graphitization by means of a dilatometer.[2] Typical evidence of the accelerating effect of copper on first-stage graphitization was obtained on material of the following composition to which none, 1.33, 1.73, and 2.94 per cent copper was added; carbon, 2.40 per cent; silicon, 1.01 per cent; manganese, 0.31 per cent; phosphorus, 0.144 per cent, and 0.75 per cent sulphur.

11. Expansion measurements by the dilatometer method showed first-stage graphitization upon prolonged heating at 1700 degrees Fahr. to complete itself within the following intervals: no copper, 8 hours; 1.33 per cent copper, 5.2 hours; 1.73 per cent copper, 4.0 hours; and 2.94 per cent copper, 2.4 hours.

12. This and other tests have established that the apparent period for first-stage graphitization within the temperatures of 1550 degrees and 1700 degrees Fahr. was reduced about 25 per cent by 1 per cent copper and about 50 per cent by 1.5 to 1.7 per cent copper. Unlike Lykkin,[3] who concluded that copper above 2 per cent produces no increased effect on first-stage graphitization, these data show progressive reduction in first-stage graphitization time with increase in copper content up to at least 3 per cent. It does appear, however, that the acceleration of the rate of graphitization brought about by copper decreases at some high copper content in white irons.

13. Using the same white irons as were used in the first-stage graphitization tests, the time required to complete the second-stage

[2] The reliability of the dilatometer method as a means for detecting decomposition of cementite and the completion of the reaction was proved by microscopic examination of the specimens.

[3] Lykkin, L., "Influence of Copper on the Graphitization Behavior of White Cast Iron," Iowa State College, JOURNAL OF SCIENCE, vol. 8, no. 1, pp. 207-210, October 1933.

graphitization was also determined. After being held at 1700 degrees Fahr. long enough to decompose the primarily cementite, the irons were cooled at a rate of 2.3 degrees Fahr. per minute to below the critical, and then maintained at 1340 degrees Fahr. until all the eutectoid cementite was decomposed. Results are as follows: no copper, 13.2 hours; 1.33 per cent copper, 6.0 hours; 1.73 per cent copper, 5.5 hours; and 2.94 per cent copper, 4.5 hours.

14. It appears that copper accelerates both stages of the graphitization equally. Lykkin[3] also confirms this conclusion.

15. The significance of accelerated graphitization in the light of plant annealing as generally practiced is somewhat more apparent than real. The gain in time of as much as 50 per cent in the first and second stages of graphitization is somewhat minimized in its effect on the total annealing cycle by the period required to heat and cool the ovens. Nevertheless, the presence of copper, concomitant with its accelerated graphitization effect on white iron, would give greater assurance of complete malleableization under circumstances that normally would produce iron insufficiently annealed.

16. With the entire production of a foundry on copper malleable iron, advantage of the graphitizing effect of copper to shorten the anneal may be taken with a likely total saving in time, fuel, fixed and capital charges, and so forth, amounting to more than the total cost of the copper at present market prices. With these savings, there is the additional advantage of a product of higher strength, one less susceptible to intergranular embrittlement and one which, for special purposes, may be still further strengthened by precipitation hardening. It is conceivable that the annealing period in large ovens could be shortened as much as 20 per cent by 1.5 per cent copper in the iron. Yet on the basis of utilizing the accelerating effect of copper to its fullest degree, perhaps the short cycle annealing operations offer the greatest opportunities.

## Mechanical Properties of Copper-Malleable Iron

17. The presence of copper does not markedly influence the structure of malleable cast iron except that it tends to refine the grain and produce smaller and therefore a greater number of graphite nodules. The effect of copper on mechanical properties must, therefore, chiefly relate to the influence of its presence upon the ferritic matrix.

18. The solid solubility of copper in pure iron at room tem-

perature is variously given between 0.4 and 0.5 per cent, (at 1490 degrees Fahr., it is given as about 3.4 per cent) and all copper in excess of this, if permitted, will separate as tiny microscopic or sub-microscopic particles within the ferrite grains. The dissolved copper has only a moderate effect upon the mechanical properties of the malleable cast iron. It is not until more than 0.5 per cent copper is present that these properties begin to increase materially. The magnitude of the changes continues to increase, until the copper content is about 1.25 to 1.5 per cent beyond which greater percentages again only moderately affect the properties.

19. The effect of the percentage of copper on mechanical properties of laboratory-made malleable cast iron is illustrated in Table 1, and in Fig. 2. The properties in this table represent averages obtained on two specimens. Bars were cast to pattern similar to one adopted by the Malleable Iron Research Institute. All bars were annealed in a plant oven along with other castings.

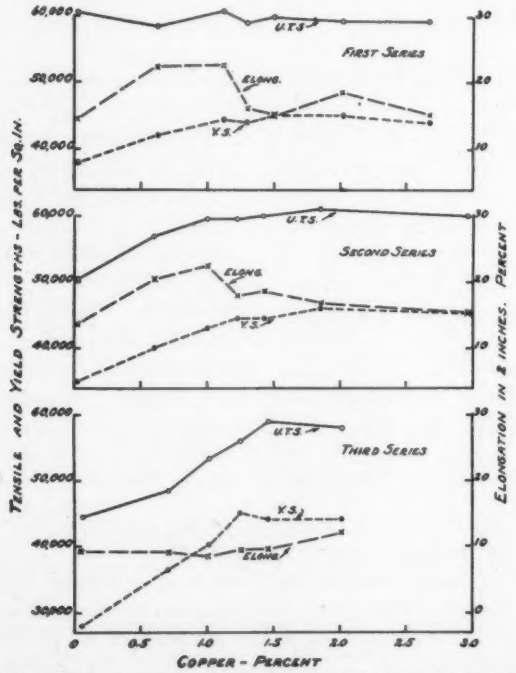


FIG. 2—MECHANICAL PROPERTIES OF LABORATORY-MADE MALLEABLE IRON CONTAINING COPPER.

**Table 1.**

MECHANICAL PROPERTIES OF MALLEABLE CAST IRON CONTAINING COPPER

| Heat | Chemical composition. *per cent | | | | | Tensile Strength, lb./sq. in. | Yield strength, lb./sq. in. | Elongation per cent in 2 in. |
|---|---|---|---|---|---|---|---|---|
| † | C | Si | Mn | P | Cu | | | |
| 1—22 | 2.36 | 0.94 | 0.27 | 0.132 | 0.031 | 60,500 | 38,000 | 14.5 |
| 1—34 | 2.31 | 1.08 | 0.22 | 0.109 | 0.63 | 58,500 | 42,000 | 22.2 |
| 1—35 | 2.27 | 1.11 | 0.22 | 0.106 | 1.12 | 61,000 | 44,500 | 22.5 |
| 1—41 | 2.38 | 1.13 | 0.28 | 0.128 | 1.30 | 59,000 | 44,000 | 16.0 |
| 1—44 | 2.36 | 1.10 | 0.26 | 0.124 | 1.50 | 60,000 | 45,000 | 15.0 |
| 1—45 | 2.33 | 1.10 | 0.27 | 0.122 | 2.01 | 59,500 | 45,000 | 18.5 |
| 1—47 | 2.34 | 1.04 | 0.26 | 0.119 | 2.68 | 59,500 | 44,000 | 16.0 |
| 2—46 | 2.43 | 1.27 | 0.31 | 0.141 | 0.042 | 50,500 | 35,000 | 13.8 |
| 2—29 | 2.29 | 1.19 | 0 25 | 0.105 | 0.60 | 57,000 | 40,000 | 20.2 |
| 2—30 | 2.31 | 1.22 | 0.25 | 0.110 | 1.00 | 59,500 | 43,900 | 22.5 |
| 2—42 | 2.29 | 1.29 | 0.26 | 0.138 | 1.22 | 59,500 | 44,500 | 17.8 |
| 2—31 | 2.36 | 1.29 | 0.26 | 0.123 | 1.42 | 60,000 | 44,500 | 18.5 |
| 2—32 | 2.34 | 1.28 | 0.25 | 0.122 | 1.85 | 61,000 | 46,000 | 16.7 |
| 2—38 | 2.26 | 1.24 | 0.24 | 0.125 | 2.97 | 60,000 | 45,500 | 15.3 |
| 3— 9 | 2.78 | 0.92 | 0.27 | 0.127 | 0.07 | 44,500 | 28,000 | 9.3 |
| 3—10 | 2.77 | 0.92 | 0.25 | 0.130 | 0.72 | 48,500 | 36,500 | 9.0 |
| 3—11 | 2.76 | 1.02 | 0.28 | 0.130 | 1.02 | 53,500 | 40,000 | 8.5 |
| 3—12 | 2.76 | 1.01 | 0.26 | 0.128 | 1.25 | 56,000 | 45,000 | 9.5 |
| 3—13 | 2.64 | 0.95 | 0.25 | 0.123 | 1.46 | 59,000 | 44,000 | 9.5 |
| 3—14 | 2.64 | 0.92 | 0.24 | 0.117 | 2.02 | 58,000 | 44,000 | 12.0 |

†First number in heat number indicates series.
*Sulphur content of the iron ranged from 0.025 to 0.030 per cent.

20. Perhaps of greatest interest are the effects of copper on the yield strengths. All irons with more than 1.25 per cent copper have a yield strength of 44,000 to 46,000 lb. per sq. in. which is obtained more or less regardless of the quality of the base iron. Provided that no mottled areas appear in the white iron, it remains unchanged to at least 3 per cent copper.

21. The tensile strength of the irons with 1.25 per cent copper or more also tend to reach a constant value, about 60,000 lb. per sq. in.

22. Disregarding the elongation values of the unalloyed irons of the first and second series, it is generally observed that copper to some degree reduces the elongation values.

23. The exceptional increase in tensile yield strengths brought about by copper in the third series, the high carbon iron, is unique

**Table 2.**

MECHANICAL PROPERTIES OF COMMERCIAL COPPER BEARING IRON

| No. | Copper per cent | Tensile strength, lb./sq. in. | Yield strength, lb./sq. in. | Elongation, per cent in 2 in. | Brinell Hardness |
|---|---|---|---|---|---|
| 1 | 0 | 56,000 | 36,000 | 14.0 | 121 |
| 2 | 1.33 | 64,000 | 48,500 | 12.0 | 135 |
| 3 | 1.73 | 63,000 | 47,000 | 11.2 | 134 |
| 4 | 2.25 | 61,000 | 47,000 | 10.0 | 137 |
| 5 | 2.94 | 63,000 | 47,500 | 9.5 | 137 |

and of some industrial importance. Here, by the simple expedient of alloying the iron with 1.25 per cent copper, a low shrinkage and easily machinable material is made to possess the strength properties of the low carbon malleable iron. Only its elongation is not improved. Copper is particularly effective in raising the yield and tensile strengths of the weaker high carbon irons.

24. While the effect of copper on the mechanical properties of malleable cast iron as here determined was observed on laboratory-made materials, the same general observations are confirmed by tests on a plant-made iron whose average properties are given in Table 2 and in Fig. 3. Composition of the iron was 2.40 per cent carbon; 1.01 per cent silicon; 0.31 per cent manganese; 0.075 per cent sulphur and 0.144 per cent phosphorus.

25. In Table 2 the tensile and yield strengths assume constant values of 61,000 to 64,000 and 47,000 to 48,500 lb. per sq. in. respectively with 1.33 per cent or more copper in the iron. The Brinell hardness value increases with copper and does not rise

further with the addition of more than 1.33 per cent, and the elongation values progressively fall with copper content.

26. No decided benefits accrue to mechanical properties upon adding more than 1.25 to 1.50 per cent copper to malleable cast iron.

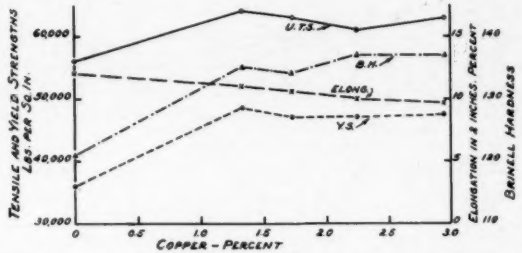


FIG. 3—MECHANICAL PROPERTIES OF COMMERCIAL MALLEABLE CAST IRON CONTAINING COPPER.

27. *Endurance Limit.* The endurance properties of malleable cast iron are improved by copper in the same proportion as the tensile strength is increased. That such is the case is shown by values given in Table 3 for the endurance limit and ratio of malleable cast iron with and without copper. The endurance values were obtained from the stress-cycle curves shown in Fig. 4.

28. *Modulus of Elasticity.* The modulus of elasticity of malleable cast iron, determined from stress-deformation values, is unaffected by copper.

29. *Intergranular Embrittlement.* There is a definite tendency for copper to reduce the susceptibility of malleable cast iron to "galvanizing" or intergranular embrittlement. Its effect is

**Table 3.**

EFFECT OF COPPER ON ENDURANCE PROPERTIES OF IRON

| Chemical composition | | | | Endurance properties | | |
|---|---|---|---|---|---|---|
| C | Si | Mn | Cu | Endurance limit, lb./sq. in. (A) | Tensile strength, lb./sq. in. (B) | Endurance ratio $\frac{A}{B}$ |
| 2.43 | 1.27 | 0.31 | 0.042 | 27,000 | 50,500 | 0.535 |
| 2.48 | 1.10 | 0.31 | 1.24 | 30,000 | 60,300 | 0.498 |
| 2.26 | 0.90 | 0.28 | 1.12 | 32,000 | 57,750 | 0.554 |

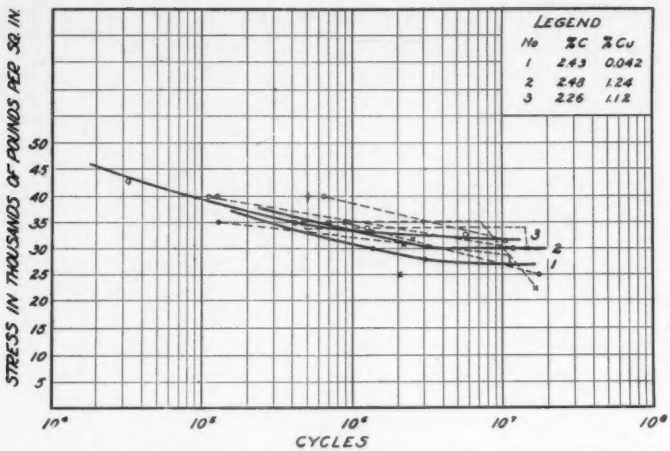


FIG. 4—THE ENDURANCE STRENGTH OF ANNEALED MALLEABLE CAST IRON CONTAINING COPPER.

convincingly shown with Charpy impact specimens heat-treated as follows:

1. As annealed.
2. Heated to 840 degrees Fahr. for ½ hour and water-quenched.
3. Heated to 1200 degrees Fahr. for 1 hour and water-quenched.
4. Heated to 1200 degrees Fahr. for 1 hour and water-quenched, reheated to 840 degres Fahr. for ½ hour and water-quenched.

30. In Table 4, the Charpy impact values of specimens heat-

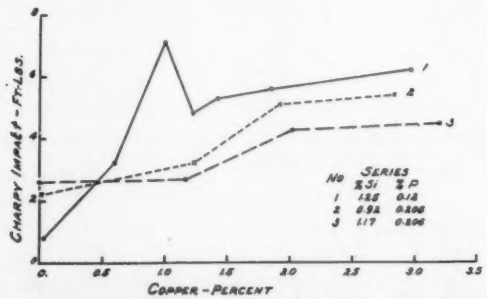


FIG. 5—CHARPY IMPACT PROPERTIES OF COPPER-BEARING MALLEABLE CAST IRON AFTER WATER-QUENCH FROM 840 DEGREES FAHR.

treated in this manner are the averages obtained on three specimens. For greater clearness, the Charpy values obtained after quenching from 840 degrees Fahr. are plotted in Fig. 5.

31. The change in impact values of the annealed specimens after they are heated to 840 degrees Fahr. and quenched is a measure of their susceptibility to embrittlement. It will be noted from Table 4 and the curves of Fig. 5, that losses in impact resistance after this treatment are effectively reduced by copper. None of the irons is susceptible to embrittlement after the generally applied corrective treatment of quenching from 1200 degrees Fahr.

**Table 4.**

CHARPY IMPACT VALUES OF MALLEABLE IRON SHOWING EFFECT OF COPPER ON INTER-GRANULAR EMBRITTLEMENT

| Heat | Chemical composition, | | | | | Average Charpy impact values, ft.-lb. | | | |
|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | P | Cu | Annealed | Heated to 840°F. and quenched | Heated to 1200°F. and quenched | Heated to 1200°F. and Quenched; reheated to 840°F. and quenched |
| 46 | 2.43 | 1.27 | 0.31 | 0.141 | 0.042 | 4.8 | 0.8 | 4.9 | 5.3 |
| 29 | 2.29 | 1.19 | 0.25 | 0.105 | 0.60 | 8.1 | 3.2 | 7.8 | 8.3 |
| 30 | 2.31 | 1.22 | 0.25 | 0.110 | 1.00 | 8.0 | 7.1 | 7.9 | 8.2 |
| 42 | 2.29 | 1.29 | 0.26 | 0.138 | 1.22 | 7.2 | 4.8 | 6.9 | 7.1 |
| 31 | 2.36 | 1.29 | 0.26 | 0.123 | 1.42 | 7.3 | 5.3 | 6.8 | 7.2 |
| 32 | 2.34 | 1.28 | 0.25 | 0.122 | 1.85 | 7.0 | 5.6 | 7.1 | 7.5 |
| 38 | 2.26 | 1.24 | 0.24 | 0.125 | 2.97 | 6.9 | 6.2 | 7.1 | 7.3 |
| 1A | 2.36 | 0.92 | 0.32 | 0.206 | 0 | 4.4 | 2.2 | ... | ... |
| 3A | 2.36 | 0.92 | 0.32 | 0.206 | 1.23 | 5.4 | 3.2 | ... | ... |
| 5A | 2.36 | 0.92 | 0.32 | 0.206 | 1.92 | 5.7 | 5.1 | ... | ... |
| 7A | 2.36 | 0.92 | 0.32 | 0.206 | 2.84 | 5.8 | 5.4 | ... | ... |
| 9A | 2.36 | 1.17 | 0.32 | 0.206 | 0 | 5.7 | 2.6 | ... | ... |
| 11A | 2.36 | 1.17 | 0.32 | 0.206 | 1.17 | 5.2 | 2.7 | ... | ... |
| 13A | 2.36 | 1.17 | 0.32 | 0.206 | 2.01 | 5.2 | 4.3 | ... | ... |
| 15A | 2.36 | 1.17 | 0.32 | 0.206 | 3.20 | 5.6 | 4.5 | ... | ... |

32. While tensile properties remain relatively unaltered with quantities of copper above 1.25 to 1.50 per cent, it may require several per cent copper to insure freedom from intergranular embrittlement in some malleable cast irons.

33. The evidence is ample that copper modifies intergranular embrittlement in malleable cast iron of variable silicon and phosphorus contents. Copper is not a cure for inter granular embrittlement, but the modification and suppression of the embrittlement which it effects are of considerable industrial importance and, if full use is made of its action, the amount of malleable iron which must be specially heat-treated before zinc-coating or galvanizing to insure freedom from embrittlement would be enormously reduced.

34. Because of the decreasing solubility of copper in iron (from about 3.4 per cent at 1490 degrees Fahr. to about 0.5 per

cent at room temperature), certain copper-bearing malleable irons are amenable to precipitation hardening. However, to have them respond to these treatments they must contain more than the maximum amount of copper which is soluble in iron, under equilibrium conditions, at room temperature. Usually, no hardening is experienced with a copper content less than 0.65 per cent.

## PRECIPITATION HARDENING IN COPPER MALLEABLE CAST IRON

35. Some improvements in strength and hardness are gained merely by reheating the annealed iron for several hours at 850 to 1000 degrees Fahr., but to harden the iron effectively by subsequent precipitation, a solution treatment to dissolve a reasonable quantity of copper, should precede the reheating. The solution heat treatment to dissolve some of the copper precipitated during the slow cooling following the anneal should be carried out at a temperature just below the lower critical temperature. This avoids carbon absorption, yet permits a substantial solution of copper. Copper is retained in solution even at reasonably slow rates of cooling as, for instance, during air-cooling.

36. By reheating the solution-treated irons to 850 to 1000 degrees Fahr. for a time determined by the temperature and the degree of hardening sought, copper (according to the usual explanation of precipitation-hardening phenomena) is precipitated as particles of sub-microscopic size. These disseminated particles produce hardening of the irons and increase their tensile and yield strengths. A few data are included in Table 5 to demonstrate the precipitation-hardening effect in specimens of iron that were given a solution treatment for 1 hour at 1350 to 1375 degrees Fahr., then reheated for 3 hours at 930 degrees Fahr.

37. In Fig. 6, the changes in properties which occur upon precipitation hardening, subsequent to the solution treatment, are plotted in relation to the copper contents of the irons. The abruptness in the trend of the curves between 0.63 and 1.25 per cent copper is distinct evidence of the precipitation-hardening effect.

38. The average tensile and yield strengths and hardness of the malleable cast irons are slightly increased, and the elongation practically unaffected, by the solution treatment, indicating that a rather small amount of carbon was redissolved and that part of the copper had been brought into solution at the temperature chosen. Some precipitation hardening occurred on reheating for

**Table 5.**

Mechanical Properties of Precipitation-Hardened Malleable Cast Iron

| Heat | Chemical composition | | | | | Tensile strength, lb./sq. in. | Yield strength, lb./sq. in. | Elongation, % in. 2 in. | Brinell Hardness | Treatment |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | P | Cu | | | | | |
| 22 | 2.36 | 0.94 | 0.27 | 0.132 | 0.031 | 60,500 | 38,000 | 14.5 | 121 | Annealed |
| | | | | | | 63,000 | 44,000 | 17.7 | 133 | 1350–1375°F. |
| | | | | | | 62,000 | 41,000 | 16.3 | 121 | Reheated 930°F. |
| 34 | 2.31 | 1.08 | 0.22 | 0.109 | 0.63 | 58,500 | 42,000 | 22.2 | 121 | Annealed |
| | | | | | | 61,000 | 45,500 | 23.7 | 134 | 1350–1375°F. |
| | | | | | | 60,500 | 44,000 | 24.5 | 130 | Reheated 930°F. |
| 41 | 2.38 | 1.13 | 0.38 | 0.128 | 1.30 | 58,500 | 44,000 | 15.5 | 128 | Annealed |
| | | | | | | 60,000 | 48,000 | 15.7 | 141 | 1350–1375°F. |
| | | | | | | 65,500 | 54,000 | 14.0 | 159 | Reheated 930°F. |
| 45 | 2.33 | 1.11 | .027 | 0.122 | 2.01 | 59,500 | 45,000 | 18.5 | 128 | Annealed |
| | | | | | | 62,000 | 50,000 | 18.5 | 139 | 1350–1375°F. |
| | | | | | | 70,000 | 59,000 | 15.2 | 165 | Reheated 930°F. |
| 12 | 2.76 | 1.01 | 0.26 | 0.128 | 1.25 | 56,000 | 45,000 | 9.5 | 128 | Annealed |
| | | | | | | 56,500 | 47,000 | 11.5 | 134 | 1350–1375°F. |
| | | | | | | 65,000 | 57,000 | 7.2 | 159 | Reheated 930°F. |
| 29 | 2.29 | 1.19 | 0.25 | 0.105 | 0.60 | 57,000 | 40,000 | 20.2 | 122 | Annealed |
| | | | | | | 59,000 | 45,000 | 22.7 | 134 | 1350–1375°F. |
| | | | | | | 60,000 | 44,500 | 22.7 | 133 | Reheated 930°F. |

3 hours at 930 degrees Fahr. Malleable irons containing 0.6 per cent copper or less showed no alteration in properties, but those containing 1 per cent copper or more had their tensile and yield strengths increased by 2,000 to 10,000 lb. per sq. in. with only a small though noticeable reduction in elongation.

39. While it may be impracticable for many casting manufacturers to take advantage of the precipitation-hardening effect of copper in malleable iron with their present equipment, never-

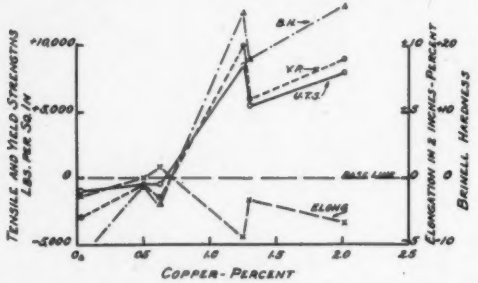


FIG. 6—CHANGES IN PROPERTIES OF MALLEABLE CAST IRON CONTAINING COPPER AFTER SOLUTION TREATMENT FOR 1 HOUR AT 1350 TO 1375 DEGREES FAHR., FOLLOWED BY PRECIPITATION HARDENING FOR 3 HOURS AT 930 DEGREES FAHR. PROPERTIES OF THE SOLUTION TREATED IRONS USED AS A BASE. PLOTTED VALUES ARE DIFFERENCES BETWEEN THESE PROPERTIES AND THE PROPERTIES AFTER PRECIPITATION HARDENING.

theless, this potential source of increased strength is available. It is suggested that materials so treated may eventually prove themselves of value as readily machined high-strength irons.

40. From the data presented, it would appear that a malleable iron of about 2.35 per cent carbon, 1.10 per cent silicon, 1.25 per cent copper, 0.30 per cent manganese, 0.07 per cent sulphur, 0.15 per cent phosphorus, in plant production, should allow cutting 10 hours off the annealing time (3 hours in the first stage and 7 hours in the second stage of graphitization at an annealing temperature of 1700 degrees Fahr.). The material should have about 59,000 lb. per sq. in. tensile strength, 44,000 lb. per sq. in. yield strength, 30,000 lb. per sq. in. endurance limit, 16 to 22 per cent elongation, and 130 Brinell hardness, and should possess acceptable resistance to galvanizing embrittlement without quenching.

41. By solution and precipitation treatments, the material could be brought to 65,000 lb. per sq. in. tensile strength, 54,000 lb. per sq. in. yield strength, 14 per cent elongation, 160 Brinell hardness.

42. The question might be raised whether the improvement in the yield strength from say 36,000 to 44,000 lb. per sq. in. by the use of copper could not be brought about without expense; in other words, whether the saving due to decrease in annealing time would not at least balance the cost of copper and justify putting copper into the whole product of a given plant, so that the annealing schedule could make use of the quick-annealing properties of copper malleable without having to be held back to accommodate slower-annealing non-alloyed malleable. The further increase to 54,000 lb. per sq. in. yield strength could be obtained by precipitation hardening if desired. While the elongation is somewhat decreased as these improvements in yield strength are obtained, the serviceability for uses where toughness is required is not decreased, as judge by impact resistance or by the area under the stress-strain diagram.

43. To the virtues of reasonable toughness and ready machineability of ordinary malleable, copper-alloyed malleable adds that of a yield strength equal to that of the regular grade of annealed carbon-steel casting.

## SUMMARY

44. The foregoing statements may be summarized as follows:

1. Copper is easily alloyed with the iron in the ladle or spout.

2. Molten iron can take into solution at least 3 per cent copper.

3. Three-tenths per cent copper adds little to the mechanical or physical properties of malleable iron, but 0.7 to 1.25 or 1.50 per cent benefits it.

4. Copper does not change the fluidity or shrinkage of iron, nor does it increase cracking. The structure is not markedly influenced by copper.

5. Graphitization is considerably accelerated by copper, equally in the first and second stages, and the cost of the copper may be overbalanced by the benefits derived.

6. Copper improves the endurance properties of iron and reduces its susceptibility to intergranular embrittlement.

7. Mechanical properties of malleable iron with seven-tenth per cent or more copper are improved by precipitation-hardening.

8. Plant tests confirmed the findings of laboratory tests.

ACKNOWLEDGEMENT

45. The writers wish to express their appreciation to the Copper and Brass Research Association, by whom these investigations were sponsored and supported, to E. W. Palmer, of the American Brass Company, and to A. W. MacLaren and D. E. Krause, of Battelle Memorial Institute, who rendered valuable assistance in these investigations, and to the Ohio Malleable Company for supplying specimens of commercial copper-bearing malleable iron.

## DISCUSSION

O. W. ELLIS[1], (*Submitted in Written Form*): This useful paper has proved of considerable interest to us at the Ontario Research Foundation, as we have been working on the question of the effect of various elements upon the resistance to wear of white cast iron and in this connection have been carrying out annealing experiments on the irons which we have produced. We are able to support many of the claims made by the authors—among them, for example, that copper is easily alloyed with iron in the furnace and in the ladle. I think that it can be said with a fair degree of certainty that iron containing approximately 2 per cent carbon, 0.50 per cent manganese, and 0.75 per cent silicon can dissolve at least 4 per cent copper.

A 4 per cent copper alloy of the above composition has been examined quite carefully by us and has been found to be uniform in structure throughout. An attempt was made by us to produce an 8 per cent copper alloy (otherwise of the same composition), but copper was found free in the castings produced. Analysis of portions of the alloy, apparently containing no free copper, gave 5¼ per cent. Whether this 5¼ per cent represents the limit of solubility of copper in iron of this composition is, however, not known at the moment.

We find that the addition of copper to white cast iron lowers its resistance to wear. The tests which we have conducted in this connection have been carried out in ball mills, using 1-inch, sand-cast balls of the various alloys and carborundum of standard size as an abrasive, 30 per cent (by weight) of water being introduced into the charge for the purpose of increasing the rate of erosion.

That copper increases the rate of graphitization of iron, is indicated by the results shown in Figs. 1 and 2. Fig. 1 is based on the results of chemical analyses of alloys containing the proportions of manganese and silicon referred to previously and, in every case, less than 0.02 per cent each of sulphur, phosphorus, and aluminum (aluminum was used as a deoxidizer). In all experiments, the alloys were heated to 875 degrees Cent. (1607 degrees Fahr.) for the number of hours shown in the chart. They were then cooled during a period of about 6 hours to 725 degrees Cent. (1337 degrees Fahr.) and then were held at that temperature for

[1] Ontario Research Foundation, Toronto, Can.

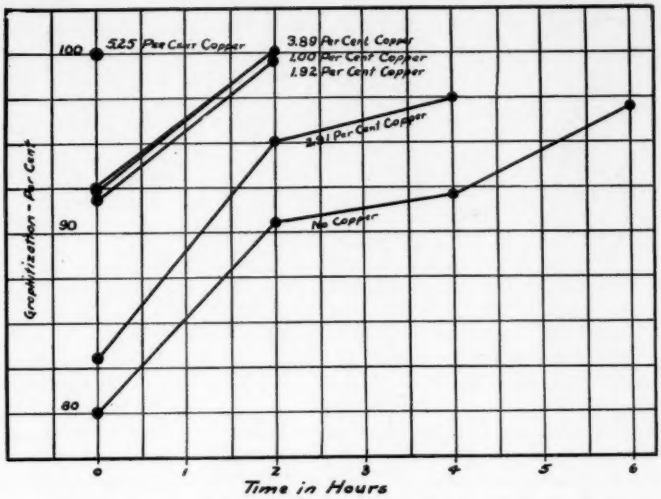


FIG. 1—EFFECT OF COPPER ON GRAPHITIZATION IN CHILL CASTINGS.

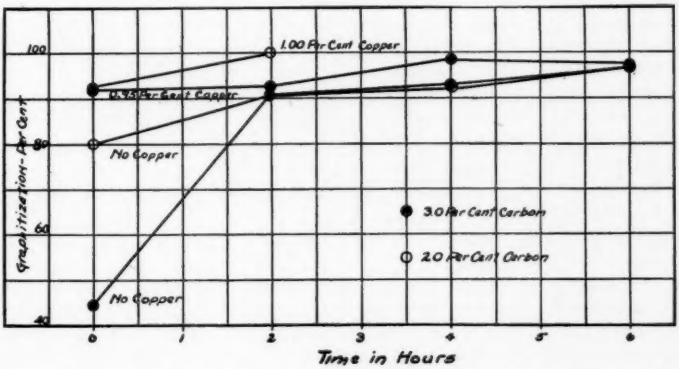


FIG. 2—EFFECT OF COPPER ON IRONS CONTAINING 2.0 AND 3.0 PER CENT CARBON.

6 hours, after which they were removed from the furnace. The curves shown in Fig. 1 indicate quite clearly that graphitization is considerably accelerated by copper under the conditions referred to in the last sentence. The peculiar results for the alloy containing 2.91 per cent of copper have not as yet been satisfactorily explained by us. We are still striving to discover why the rate of graphitization of this particular series should have been so much lower than that, for example, of the

alloys containing 1.00 per cent, 1.92 per cent, 3.89 per cent, respectively. It may be well to point out that the results shown in Fig. 1 apply to chill castings of the alloys concerned and not to sand castings.

In Fig. 2 are shown the effects of copper upon the graphitization of chill white iron containing both 2 per cent and 3 per cent of carbon. Here again, the fact that graphitization is accelerated by the addition of copper is made quite clear.

We have made no mechanical tests other than hardness tests on the alloys which we have investigated. We have found, however, that the Brinell hardness numbers of malleable iron containing copper are greater than those of malleable iron containing no copper.

E. TOUCEDA[2], (*Submitted in Written Form*): The writer has read with interest the valuable contribution of Messrs. Lorig and Smith. To the end that he will not be misunderstood and as an introduction to his remarks he would explain that the aim of the group of malleable iron plants he represents in the capacity of consulting metallurgical engineer is to broaden the field for the product. In order that this object may be achieved effectively, it is essential to produce a uniform product having such tensile and impact properties as will cause it to be selected by the trade in preference to those with which it is in competition, by reason particularly of high yield point and elongation, coupled with the greater ease with which it can be machined.

Equally important is the fact that what is wanted is not a mixture that will be safe for sections ⅝ in. thick and under, but one that can be used, without risk of graphitization, in the case of thicker sections and heavy bosses. Also, the introduction of any element in the mixture that will increase either its cost, or scrap loss due to shrink or cracks, would be regarded as a serious handicap.

It is admitted that any change in the mixture that will operate to safely shorten first and second stage graphitization is highly desirable. However, as far as the action of copper is concerned, an increase in silicon will achieve this purpose just as effectively as will the former. The advisability of using copper, therefore, appears to be dependant upon the extent to which the tensile properties may be enhanced without lowering elongation or impact values unduly, and upon the thickness of the sections.

Although the average tensile properties of test bars from the group of plants with which the writer is associated are somewhat over 54,000 lbs. per sq. in. ultimate; 35,000 lbs. per sq. in. yield point and 18 per cent in elongation, it should be borne in mind that a very substantial number of the bars of the members will average much higher than shown by these figures. Selecting the results from the test bars submitted by one of the plants of the group, during the past month we find that the average ultimate, yield point and elongation are respectively 58,282 lbs. per sq in.; 38,700 lbs. per sq. in.; 23.43 per cent. The highest and lowest of each of these properties respectively was 61,700 and 55,120 lbs. per sq. in.; 38,700 and 36,690 lbs. per sq. in. and 27.50 and 17.50 per cent. While this happens to be the highest record during this recent interval, there are

[2] Consulting Metallurgical Engineer, Malleable Iron Research Institute, Cleveland.

quite a number of other plants that almost equal these figures, and in the past some that have excelled it materially. Yield points of 43,000 lbs. per sq. in. and elongations of 35 per cent, although uncommon, have been obtained at times. It can be safely stated that should a demand arise for considerably higher tensile properties than those of the plant referred to, such could be met.

Reference to the foregoing is simply to demonstrate that without resorting to copper or other metal additions, not only can results superior to those shown by the authors be obtained, provided this is based upon a consideration of the tensile properties taken as a whole, but there would be scant danger that primary graphite would be present in any of the castings.

As the minimum yield point and elongation requirements for Class "B" steel castings have been placed at 36,000 lbs. per sq. in. and 22 per cent respectively, we can conclude that engineers are satisfied that these figures are safe.

While some of the tests shown by the authors would just get by in respect to elongation, although the yield point is exceeded by a handsome margin, the question is, would castings of substantial thickness be free from graphitization? With a knowledge of the risk involved, would an engineer feel justified in taking a chance that these hidden defects might be present. This is a real danger that would have to be met and is the reason why a shortening of the anneal through the use of very high silicon would not be attempted by the group referred to, except in the case of quite thin sections, for a jobbing foundry cannot run commercially in these days if it has to have one mixture for thin and another for heavy sectioned work.

It is well known that both copper and sulphur produce red-shortness, each apparently intensifying the action of the other as each is present in increasing amount. The writer was made painfully acquainted with the action of copper in the early days when he was chief metallurgist of the Troy Steel and Iron Company, at a time when they were using pig-iron made from copper bearing ores from Cornwall, Pa., as many billets had to be rejected due to surface inspection.

It has been shown by numerous investigators that copper acts to increase all of the tensile properties of soft and medium steel and, when this element is present in quantities of less than 0.50 per cent, that ductility is not affected. The authors of the paper under discussion have pointed out that in the case of malleable iron, when more substantial percentages of copper are present, ductility is adversely affected.

However, while the authors have shown that when the percentage of copper in the product lies between 0.70 and 1.50 per cent tensile properties are enhanced, they have furnished no data covering its effect on the strength of the iron from the start to the end of solidification, a matter of great concern to the foundryman, because even in the absence of elements that produce red-shortness, there is a critical temperature during the process of solidification or shortly afterwards when the metal is so tender that any resistance offered to its normal contraction will produce

a tear. Would not the presence of elements that make for red-shortness operate to make the metal more tender during that period?

The authors have stated that the tendency for the castings to crack is not increased by the presence of copper. The writer would be more than interested to be informed regarding the source of this information. Mention is made of this fact because he has worked indefatigably to discover a method by which the cracking tendency of various mixtures can be measured, and if the authors can throw any light on this matter they will receive the profound thanks of the great majority of the foundries.

Another factor of consequence, that has to do with the effect of copper, is its effect on the life of the molten metal, that is, will its freezing range be narrowed when the addition is at a percentage that will result in the high yield points indicated by the authors? It has always been our firm conviction that those elements that produced red-shortness have a tendency to make the metal sluggish, that is, quicken the freezing range. If this is true, then the statement made by the authors that fluidity is not lessened, can hardly be a fact. The writer would anticipate that under equal conditions of gating and heading, not only would fluidity be adversely affected, but that there would be a greater probability that shrink would be present in a casting containing 0.70 to 1.50 per cent copper, than if that element was absent.

The writer is particularly interested in the statement that an addition of 0.70 to 1.50 per cent of copper will act to suppress galvanizing embrittlement. Due to the importance of this matter to the industry, it was deemed advisable to check the validity of this statement. To this end the writer requested one of the plants to furnish him with 20 tensile test bars and 20 impact wedges of their regular product; ten of the tensile bars and ten of the wedges to be galvanized and also, to carry through the same program, with the same number of test bars and wedges that would contain 1 per cent of copper. This particular plant was selected because it has an up-to-date galvanizing plant in which it does its own work and that of many others.

It will be seen from the data in Table 1, that the average elongation of the copper-free, ungalvanized, tensile bars is 21.1 per cent as against 16.3 per cent for the galvanized, indicating that the ductility had been lessened by the galvanizing operation.

Comparing the elongation of the copper-bearing bars ungalvanized and galvanized, it is seen that the average elongation of the former is 17.94 per cent and of the latter 13.11 per cent.

On a percentage basis, the loss of ductility due to galvanizing in the copper-free bars amounts to 22.76 per cent and in the copper-bearing bars it is 26.93 per cent which does not bear out the contention of the authors.

Under the assumption that some embrittlement had been suppressed the important point in the writer's mind is that the copper-free, galvanized bars are somewhat superior to those that contain copper, that is, the former is a galvanized product that would be much more liable to be accepted than would the latter.

If now the results of the impact test are considered, it will be noted that all of the copper-free ungalvanized wedges stood 30 plus blows,

without fracture. It is impractical to test wedges on our machine that stand over 30 blows, due to the fact that there is so much curl to the wedge that it cannot be held by the tongs for additional blows. The difference in impact value between the two ungalvanized sets of wedges is immediately apparent, and the same situation exists if a comparison is made between the two sets of galvanized wedges. There is no question, therefore, in the writer's mind, but that the addition of copper not only affects adversely elongation, but also impact value.

It should be explained that wedges were selected for the impact test because the writer believes this to be a much fairer measure of impact strength than is a notched bar. Owing to the very low impact values obtained by the authors on the unheat-treated bars, the writer feels satisfied that the Charpy test specimens were not solid at the point where the notch was located. It has been his experience that in most instances the pattern used for the making of notched bars has not been so gated and headed as to produce a bar free from shrink, which has occasioned considerable controversy in connection with the Charpy and Izod impact values that have been published.

In conclusion, the writer would state that these tests confirm what is claimed by the authors in respect to ultimate strength and especially yield point, coupled with the fact that ductility is lessened.

The writer would question the accuracy of the statement that there

**Table 1**

COMPARISON OF COPPER-FREE AND COPPER-BEARING MALLEABLE IRON UNDER WEDGE IMPACT TEST. NOTE: COMPOSITION OF THE HARD IRON, SILICON 1.10, PHOSPHORUS 0.146, SULPHUR 0.077, MANGANESE 0.35, TOTAL CARBON 2.25 AND COPPER 1.02. ALL FRACTURES WERE NORMAL.

| Copper-free-Black | | | | Copper-free-Galvanized | | | |
|---|---|---|---|---|---|---|---|
| Ult. Str. lbs./sq.in. | Yield Point lbs./sq.in. | Elong % in 2 in. | Wedges No. of Blows | Ult. Str. lbs./sq.in. | Yield Point lbs./sq.in. | Elong % in 2 in. | Wedges No. of Blows |
| 57170 | 38780 | 21.50 | 30* | 56280 | 37310 | 17.50 | 22 |
| 57270 | 38700 | 20.00 | 30* | 56380 | 37810 | 17.00 | 30* |
| 57060 | 38420 | 19.00 | 19 | 55590 | 37200 | 17.50 | 30* |
| 57840 | 39040 | 22.50 | 30* | 54990 | 36890 | 14.00 | 29 |
| 56600 | 38050 | 20.00 | 30* | 54860 | 36700 | 14.50 | 27 |
| 56560 | 38320 | 25.50 | 30* | 55500 | 37550 | 17.50 | 29 |
| 55590 | 37450 | 19.00 | 30* | 55520 | 37410 | 15.50 | 30* |
| 56640 | 38250 | 22.50 | 30* | 55390 | 37700 | 16.50 | 29 |
| 57480 | 40120 | 20.00 | 30* | 56100 | 38060 | 17.50 | 30* |
| | | | | 55460 | 37380 | 15.50 | 28 |
| 1.02 Per Cent Copper Addition-Black | | | | 1.02 Per Cent Copper Addition-Galvanized | | | |
| 60580 | 43780 | 17.50 | 10 | 58150 | 40580 | 15.00 | 15 |
| 60890 | 43930 | 17.50 | 23 | 61960 | 43630 | 14.00 | 11 |
| 59360 | 43800 | 15.00 | 15 | 60280 | 43180 | 12.50 | 15 |
| 58550 | 43600 | 17.50 | 18 | 61570 | 43280 | 14.00 | 17 |
| 58480 | 43480 | 20.00 | 18 | 58320 | 40900 | 12.50 | 16 |
| 59860 | 43460 | 20.00 | 16 | 61280 | 42930 | 14.50 | 11 |
| 59290 | 41760 | 21.50 | 15 | 59440 | 40440 | 11.50 | 3 |
| 62820 | 44810 | 20.00 | 19 | 61960 | 42800 | 12.50 | 16 |
| 59450 | 43190 | 12.50 | 18 | 57500 | 38430 | 11.50 | 5 |

*Unfractured after 30 blows, limit of testing machine.

is less liability for shrinkage and cracks or that the addition of copper between 0.70 and 1.50 per cent tends to suppress galvanizing embrittlement.

The authors are to be congratulated for the work that they have done and it is hoped that they will find the time to carry on further investigations along this and other lines.

H. A. SCHWARTZ[3]: The information given by Dr. Lorig should not be passed over without adequate discussion. Inasmuch as our organization may, perhaps, have some information of its own about copper upon which to base opinions, it may not come amiss if I remark here and there on points brought up by Dr. Lorig and Prof. Touceda, even without preparation.

It seems to me that most of the paper as presented by Dr. Lorig, so far as we are able to confirm or deny, would lead us to confirm what he has to say, and in listening to Prof. Touceda's written discussion, a few things occur to me which may reconcile some differences between the authors and the discusser.

The question of whether there is or is not enough red-shortness to make castings brittle, is a question of fact, not one for speculation. The author tells us that there is no difference between copper-bearing and "plain" metal. Having seen considerable amounts of iron cast which contained 1 per cent copper, I would be inclined also to say that there is not such a difference as to be noticeable ordinarily. Whether careful statistics and investigation show a difference or not, I am not prepared to say.

There is an enormous amount of material in the literature of iron and steel dealing with the question of red shortness of copper-bearing steel and the authorities are by no means in agreement. Had I come prepared to discuss the paper, I could have brought along a considerable amount of important literature which says that copper in a steel does not produce red-shortness. I am not defending that, but saying that reputable authors take that position. Even if red-shortness be found in steel rolling, it does not follow that cracking need result on the cooling of a casting or that any effect would be evident in the presence of great amounts of primary cementite.

In regard to shortening graphitization time, there are many elements which will favor graphitization at low temperatures more than at high temperatures and it is a matter of experimental trial whether a certain amount of copper will do more good in favoring graphitization than an equal amount of silicon. One has to know, as a matter of observation, whether equivalent amounts of copper and silicon added have more effect at high or low temperature.

I am not prepared to answer the question, but I know a good many castings have been made with the intent of having the silicon reasonably high, and have had 1 per cent copper added to them without mottling.

As to the order of magnitude of impact values, the results may differ because experimenters did not use Charpy specimens of the same cross-section. I think neither the author nor the discusser mentioned how

[3] National Malleable & Steel Casting Co., Cleveland, Ohio.

deeply the specimen was notched. I know of one instance where a similar difference showed up and one person used the keyhole notch and another used the 1 mm. deep V-notch, and the order of magnitude was enormously different between the two. We cannot tell whether the gentlemen differ on this until we find out what the specimens were.

My thought is that some of the reduction of the elongation after galvanizing is the expression of the very tendency to precipitation hardening of which Dr. Lorig has spoken. I think that when metal suffers an embrittlement, the impact value goes down to half or less of what it was and if metals merely decrease in impact value because of stiffening (which may or may not be desirable, depending on what you are going to make out of them), that is, perhaps, not this intergranular brittleness so much as the question of precipitation hardening. Incidentally, I believe Dr. Lorig said that he thought the tendency to intergranular brittleness was modified somewhat and not removed by the addition of copper.

E. TOUCEDA: Dr. Lorig, did you use the regular Charpy notch or the key notch?

DR., LORIG: It was the keyhole notched specimen that was used.

I was interested in hearing the discussion of the paper, especially about some of the points which are controversial. One is the red-shortness effect of copper in steel. It is only recently that investigators began to find the real cause of this surface cracking in copper-bearing steel. I think the first descriptions of the cause, appearing in the literature, were those of two Japanese investigators, Kodama and Katoira, published in 1928. They showed definitely that it was not red-shortening at all, but was nothing more than a surface phenomenon due to the fact that iron, under oxidizing conditions, oxidized in preference to copper, leaving on the surface of the steel, a film of copper, which, at temperatures of 2000 deg. Fahr. is in the molten state. When the steel is rolled, the copper tends to penetrate into the surface grain boundaries where it destroys the cohesion between the grains, and causes them to open up to form shallow surface cracks. The amount of cracking depends, among other things, upon the amount of oxidation the steel receives.

Under reducing conditions, or under conditions where no oxide is formed, as in an atmosphere of nitrogen, the effect on surface cracking is negligible. Even when rolled at temperatures considerable above 2000 deg. Fahr., no surface cracking takes place in the steel.

These results were further confirmed in an article by Franz Nehl appearing in *Stahl und Eisen*, July 1933, in which it was shown that the effect of copper on the cracking tendencies of steel could be overcome either by heating in a reducing atmosphere or by adding nickel to the steel. Even before then, at Battelle Memorial Institute, tests were made whose results correspond exactly with those later described by Prof. Nehl. There is a preponderance of evidence that the phenomenon is not red-shortness but a surface phenomenon entirely. Therefore, any argument to the effect that copper causes red-shortening in steel, loses much of its strength.

As to the result of graphitization or mottling in white cast iron, Dr. Schwartz has already pointed out that the relation between the silicon and

the copper content, for instance, might be such as to actually give white iron where normally mottling might be expected; however, by adjustment of the composition, it should be easy to control the presence or absence of primary graphitization in white cast iron.

Dr. Ellis pointed out that he has found some of his alloys contained as much as 5 per cent copper without having any of the copper segregated. That seems to be possible in light of the work of Bucholtz and Köster and others, on the equilibrium diagram of the copper-iron system. However, little is known of the equilibrium system when carbon is added. Based on the work on the iron-copper system, one would expect a little more than 9 per cent copper to go into solution with gamma iron, and, if this is chilled rapidly, it will remain there, but if it is cooled slowly, the limit of solubility at the lower transformation temperature is 3.4 per cent. Dr. Ellis used chilled samples. It was possible, therefore, for the copper to be held in solution, so that actually the iron was supersaturated with copper.

As to the cracking of castings due to the alloying element copper, the work we did was on thin-walled cylinders, using hard, dry-sand cores, and in no case could we determine any difference in the cracking tendencies of the copper-bearing malleable as against the malleable iron containing no copper.

It is a difficult problem to determine cracking tendencies in castings. Some of the papers in the steel group a year ago, and this year, pointed out the fact that there is really very little known about the hot tearing or cracking tendencies of steel as related to composition or to molding practice. The same may be said of white cast iron.

Impact values reported in this paper compared rather favorably with the average results given in the symposium on malleable cast iron. In this bulletin, a value of 7.75 ft. lbs. was given as the average Charpy impact value. Our specimens had impact values between 8 and 6 ft. lbs.

The modification which was observed in intergrannular embrittlement, as brought about by copper, was shown in this manner. Malleable irons were selected which were known to give white fractures on annealing. To these were added copper in increasing increments and fractures of the annealed irons were observed. As the copper content of the annealed irons increased, the fractures gradually changed from those which were completely white to those which speckled and finally to those which were black.

E. TOUCEDA: I want to say a word of explanation here. Dr. Schwartz stated that he could furnish evidence to throw light on the matter of whether the effect of copper operated to cause iron to be red-short. The speaker has no practical evidence that the cracks or shrink would or would not be lessened through copper additions, but he would anticipate that these troubles would be increased, not lessened. The speaker could also furnish a great deal of data on this matter which is of a very controversial character. It was to avoid the introduction of details of this kind that the speaker made the tests that are shown in his written discussion, which tests have been based on 40 tensile test bars and the same number of test wedges. It would appear to him that the results of these tests at least indicate a disagreement between the findings of

Messrs. Lorig and Smith in respect to the claim that galvanizing embrittlement is modified.

G. M. THRASHER[4]: The fact was mentioned that an increase in the copper changed the structure from white iron, annealed structure, to a black fracture. Does Dr. Lorig mean that this will take the place of manganese in that particular instance?

DR. LORIG: I made a point that the structure of the iron without copper after malleablizing, was white. On the addition of copper, this fracture changed from a white to a speckled, and then later as copper increased, to a black normal fracture. Materials high in silicon and phosphorus were purposely chosen to give the unalloyed irons a white fracture after the anneal.

MR. THRASHER: My question was whether sulphur was so high as to cause it.

DR. LORIG: The manganese contents were at least 0.22 per cent and never above 0.35 per cent. Sulphur was about 0.03 per cent in the iron made in the laboratory. As to accounting for the white fracture, I am not certain. It is a point that has been brought up at many discussions on malleable iron, and I do not think that a satisfactory explanation has ever been given. It is a condition that exists and is recognized. Various means to overcome it are available. One is by heating the iron to a temperature of 1200 degrees Fahr. and quenching previous to galvanizing.

MR. THRASHER: What element was responsible for the white sparkling fracture in the annealed iron? In practice, I have found that annealed malleables slightly deficient in manganese content will cause such fractures with a yellowish tinge, while a very large excess of manganese will cause a sparkling fracture with a bluish tinge in these castings or heavy crystaline rim in larger sections. Phosphorus also produces white fractures at about 0.35 per cent and its effect is even noticeable in lesser amounts. I particularly want to know if Dr. Lorig has found that addition of copper to a mixture which might analyze, say, 0.09 per cent sulphur and 0.14 per cent manganese, would cause the annealed structure to be typical "black heart."

DR. LORIG: In our tests, we were dealing with fully annealed malleable iron that was annealed in a normal manner. This iron contained no more than 0.03 to 0.04 per cent sulphur and manganese between 0.25 and 0.35 per cent. Therefore, we had no experience with an iron containing 0.09 per cent sulphur and 0.14 per cent manganese, for two reasons: First, such an iron is abnormal in the sense that it contains an insufficient quantity of manganese to care for all the sulphur present, and second, we were interested only in the type of intergranular embrittlement associated with high-silicon and high-phosphorus contents. Consequently, we aimed to maintain normal amounts of manganese in the iron.

The irons with a deficient or an excess amount of manganese may show a white sparkling fracture, but it will be of an entirely different character from the fracture that is associated with intergranular em-

[4] Elmira, N. Y.

brittlement to which we refer. The latter can be corrected, usually, by heating the iron to some temperature in the neighborhood of 1200 degrees Fahr. and cooling rapidly, whereas the former will not be altered by such treatment. Therefore. it is necessary to clearly distinguish between the types and the characteristics of fractures mentioned to avoid confusion and to recognize these differences.

No one knows, with any degree of assurance, the cause for intergranular embrittlement. There are several hypotheses advanced as to the cause, but none seem adequate to explain the phenomenon in all its ramifications. We had chosen for our tests, several malleable irons with either high-phosphorus or high-silicon contents, or irons with both of these elements in more than normal proportions. Apparently, these elements have some influence on promoting intergranular embrittlement, as was shown years ago by W. R. Bean*. For clearness, perhaps "galvanizing embrittlement" should have been chosen as descriptive of the phenomenon with which we were dealing, to distinguish it from the phenomenon Mr. Thrasher had in mind.

MEMBER: Did the author investigate the resistance to corrosion of copper-bearing malleable iron? I remember that cast iron showed some slight increase against acetic acid.

DR. LORIG: A few corrosion tests were made but since they were done in the laboratory, their value is uncertain. Under atmospheric conditions, copper has an appreciable effect on increasing corrosion resistance.

E. E. GRIEST[5]: Having read Dr. Lorig's paper prior to the meeting, I listened with much interest to the discussions. To me the problem is a most interesting one. It seems to me that there is a great deal more work to be done on this subject of graphitization and increased physical properties of malleable iron. It seems to me that it is advisable to try to coordinate some of the valuable information which has been incorporated in several papers. I think it was last year that we heard a very interesting paper on the effect of superheat on the physical properties of malleable iron, and the subject of graphitization was likewise dwelt upon at some length. As I recall it, the carbon-silicon ratio was such that we would, in normal foundry practice, expect to have highly mottled iron, and yet the very high silicon and low carbon produced a high quality malleable iron without indication of primary graphite.

It seems to me that if we could have this whole subject rounded up by disinterested investigators, it would be a valuable contribution to the industry. It would seem to me that the malleable iron industry could well afford to institute a plan of investigation which would incorporate the best ideas which have been developed. Members of the malleable industry, therefore, would know what to do and would not be confused by reports of investigations, one of which might employ the use of one process or material, while another might secure equally good or better results by some other method.

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[5] Chicago Railway Equipment Co., Chicago.

*Bean, W. R., *"Deterioration of Malleable in the Hot-Dip Galvanizing Process,"* TRANSACTIONS A.I.M.E., vol. 69, p. 895 (1923).

# Controlled Directional Solidification

By George Batty,* Lansdowne, Pa.

**Abstract**

*This paper is devised to show that the simple gravitation of metal super-imposed as feed heads is not competent in many cases to produce soundness in steel castings. Correctly disposed temperature gradients in both mold and metal are essential pre-requisites to the proper functioning of gravitational feeding. Specially designed gating and heading procedure, together with details of mold manipulation, are described and the relation of molding materials to pouring temperature and pouring speed is discussed. Much that has been learned during the production of castings in manipulated molds may profitably be applied in the production of castings which are too large to be treated on any of the "reversal" methods. The author particularly desires to emphasize the eminent importance of temperature gradients.*

1. The practical foundryman, graduate of the sand pile, wonders when he reads many technical papers what it is all about. This paper is written for the practical foundryman, in simple language, with simple diagrams, to show what has been done with certain cast forms to produce sounder and better structures.

2. That the advocated procedure results in the production of cheaper as well as better castings, in many instances, is fortuitously incidental.

3. The principle of creating correctly disposed temperature gradients in both mold and metal by well devised gating and heading, amplified in some cases by mold manipulation and/or by the application of external chills is one that must lead, by reason of controlled directional solidification, to the production of sounder and more dependable steel castings.

4. In the unbiased mind there can exist no doubt as to the present and potential value of the injection of science into the steel

* Technical Director, Crucible Steel Casting Co.

Note: This paper was presented at one of the sessions on Steel Founding at the 1934 Convention of A. F. A.

castings industry, and while the scientists and their interpreters, the technicians, are well assured of the merits of their work, they must secure the enthusiastic cooperation of the practical foundryman before their researches can be profitably applied in the production of castings.

5. The paper by Briggs and Gezelius[1] is, in the opinion of the writer, one which may become—when amplified by their continued investigations—a potent factor in directing foundry practice into more accurate and efficient lines of procedure.

6. It is readily conceded that practical foundrymen, making no claims to possess scientific knowledge, have produced in large quantity the commercially satisfactory castings which have served the various consumer industries for many years and it cannot be denied that in many cases where castings have failed to render their devised service the fault has lain largely in some inadequacy of design.

7. The reputable founder is the keenest qualified critic of his own product and unhesitatingly rejects bad metal or the product of bad molding. He cannot, however, be held wholly culpable when he is compelled to mold castings of such design as present to his experienced intelligence little certainty of producing safe and serviceable articles. The question of design demands a great deal of attention but is by no means the whole answer to the problem of producing castings free from internal shrinkage cavities, hot tears and other structural weaknesses.

8. Some few statements appearing in the paper by Briggs and Gezelius must necessarily be cited in this present paper as it is the author's purpose to discuss the principle of controlled directional solidification and, by means of a few illustrations, describe what has already been accomplished in the production of certain types of castings.

## INGOT PRODUCTION AND INGOT MOLD DESIGN

9. An ingot is a casting of the simplest form, but ingot makers have adopted various expedients to secure, first, freedom from axial cavity or enclosed pipe and, second, a reduction of top-discard. Probably the most important contribution to the production of internally sound ingots, with a marked reduction in the amount of top-discard, was H. Brearley's introduction of the tapered ingot

[1] Briggs, C. W., and Gezelius, R. A., *"Studies on Solidification and Contraction and Their Relation to the Formation of Hot Tears in Steel Castings,"* TRANSACTIONS A.F.A., vol. 41 (1933) pp. 385-424.

mold producing an ingot of appreciably greater area at the top than at the base.

10. Until early in the present century practically all crucible steel was cast in parallel-sided molds, and the "teeming" of the steel required both skill and good judgment to produce the requisite temperature gradient in the ingot to prevent serious unsoundness in the form of an attenuated axial weakness below the "dozzle" or hot-top.

11. In ingot production it is practicable to establish a fairly definite ratio of length to mean diameter, but in steel castings it is not possible to establish any such arbitrary ratio. In fact, many steel castings are so designed that parts of the piece present the undesirable features of the "small-end-up" ingot. Greater dangers are attendant upon top-pouring into sand molds to produce castings than top pouring into chill molds to produce ingots. Orthodox steel foundry practice involves leading the metal by one or more gates into the lower levels of the mold.

## SOLIDIFICATION IN MOLD

12. Steel solidifies primarily as a result of the progressive transfer of heat from metal to mold. In ingot practice it is practicable also, as a function of mold design, to promote a selective graduated chill effect by having molds of taper wall section, the heaviest section being at the base. Brearley graphically indicates the progress of solidification of such an ingot in such a mold by successive inscribed lines approximately parallel to the mold faces.

13. Despite the accruing advantages of modification of ingot an ingot mold design, the writer believes that Arthur Brearley went even farther and applied for a patent covering procedure which involved suspending the ingot mold—or a group of molds—in a cradle and gating into the wide end of the ingot mold which was lined with a brick hot-top. A vent was provided in the small end of the mold in order to permit the escape of the mold atmosphere and this vent sealed itself when penetrated by metal as the mold filled. After the mold or molds were filled, the "trumpet" or downgate was sealed and the mold or molds reversed through 180 degrees. Such ingots were poured "big end down" but, after reversal through 180 degrees, became orthodox "big end up" ingots with the added advantage of a pronouncedly favorable temperature gradient in both mold and metal.

14. The writer saw this specification of the Brearley patent some time after he had devised and operated a system of complete

reversal of sand molds in the production of certain types of steel castings and while he has no knowledge of the Brearley method of ingot production, as outlined in the patent specification, being applied commercially it can be said that a number of steel foundries are at the present time making use of what is called the total reversal system in the production of some types of steel castings.

15. In the exposition of the principle of achieving controlled directional solidification it is considered advisable to detail, by

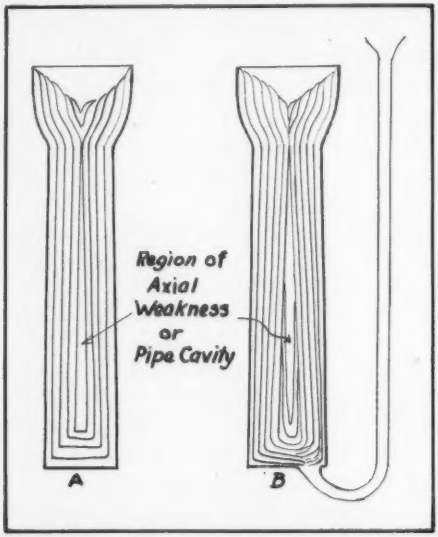


FIG. 1—STEEL INGOT FORMS SHOWN WITH PROGRESSIVE SOLIDIFICATION INDICATED BY INSCRIBED LINES ON THE BREARLY METHOD. (*A*) PARALLEL-SIDED, TOP POURED, SAND MOLD INGOT. (*B*) BOTTOM GATED SAND MOLD INGOT.

means of diagrams, some simple forms and in Figs. 1 and 2, ingots are shown with the progressive solidification indicated by inscribed lines on the Brearley method. Fig. 1*A* shows a parallel-sided top poured ingot produced in a sand mold and Fig. 1*B* a bottom-gated ingot from a sand mold.

16. Fig. 2 illustrates an example of 180 degree reversal of an ingot casting in a sand mold. In examples shown in Fig. 1, it will be noted that the feed heads are of the orthodox enlarged type, having a head of cross-sectional area greater than the cross-sectional area of the casting upon which it is imposed, while the example in Fig. 2 is provided with what is known as the reverse taper head.

17. It should be understood that the rate of filling the molds,

in the three examples illustrated on Figs. 1 and 2, is approximately identical, speed of casting being assessed by the term "rise of metal in mold per second." The speed or rate at which a mold is filled is likely to have some important influence upon the ultimate soundness of the casting and while many foundrymen are committed to the principle of filling the mold quickly with metal at as low a temperature as is practicable, the writer will not accord his support to that principle in all cases.

18. In the production of many types of steel castings it is

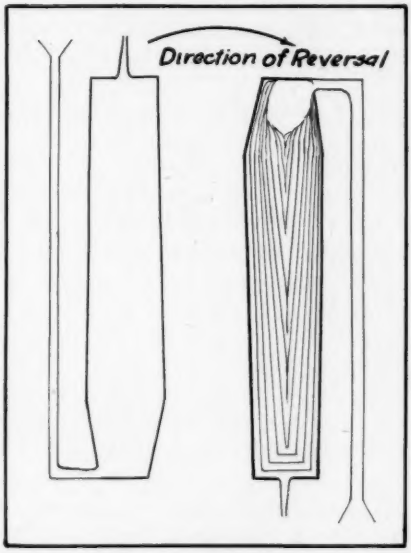


FIG. 2—AN EXAMPLE OF 180 DEGREE REVERSAL OF AN INGOT CASTING IN A SAND MOLD.

essential, because of the nature of the molding materials, to introduce the metal quietly into the lower levels of the mold and in such circumstances the mold may have to be filled rapidly in order to avoid the creation of a serious adverse temperature gradient in both mold and metal. In discussing this, we can profitably return to our figures of sand cast ingots shown on Figs. 1 and 2.

19. In top pouring, as illustrated on Fig. 1*A* there will be no pronounced temperature gradient produced in the mold in the act of pouring, but there would be a serious danger of inclosed pipe unless a head of enlarged section were applied. The inscribed lines on Fig. 1*A* indicate the effect of the enlarged head in that

the casting would appear sound after the removal of the head, but experience has revealed that there is a tendency to fine secondary pipe below the head. The area indicated as the region of axial weakness or pipe cavity is not intended to show the form of the pipe but marks that portion of the ingot which will still be liquid or in the mushy state when solidification is complete a short distance below the head.

20. The inscribed lines on Fig. 1*B* indicate approximately the progressive solidification of the bottom poured ingot and as this example may be considered typical of many steel castings, it is considered proper here to emphasize the importance of the duration of metal contact with mold in the process of filling the mold.

## RELATION OF METAL TEMPERATURE TO POURING SPEEDS

21. The practical steel foundryman knows that he must use metal of a temperature at least adequate to ensure that his mold will be cleanly and completely filled. Any "faint running" or pronounced "cold shuts" may lead to the rejection of the casting. He knows also that it is at the parts of the mold remote from the in-gate or in-gates that faint running or cold shuts are most likely to occur and, further, he daily sees examples of the effect of mold upon metal in that the metal tends to crust or fails to flow freely in risers or feed heads remote from the pouring gate. All this is evidence that the metal is cooled in its passage through the mold and this involves the acknowledgment of the fact that such cooling of the metal is resultant upon the transferrence of heat from metal to mold. The heat transferrence must be, to some considerable extent, proportionate to the duration of contact of metal with mold and it therefore necessarily follows that the lower levels of the mold are subject to more heating by the cast metal than are the upper levels of the mold.

22. Reverting to Fig. 1*B*, it can logically be argued that the upper surface of the casting is the coolest metal while the base of the casting is the hottest metal. The temperature gradient in the metal is in the wrong direction to promote soundness. Added to this is the fact that the mold adjacent to the base of the casting is the hottest part of the mold while the mold adjacent to the upper layer of metal is the coldest part of the mold in contact with cast metal. The temperature gradient of the mold is therefore in the wrong direction and on this orthodox system of pouring we have cool metal in the upper levels of the casting in con-

tact with a relatively cold mold and hot metal in the lower levels of the casting in contact with a mold so heated as to represent considerable insulation. In such conditions it is obvious that a casting of the type illustrated may be seriously afflicted with internal shrinkage cavity.

23. The degree of adverse temperature gradient in both mold and metal will be related to the speed at which the mold is filled and it is certain that there has been some substantial warrant for the adoption of the principle "pour quickly with metal as cool as possible." It must be conceded, however, that in many cases the application of this principle, even when carried to its ultimate practical limit, has failed to produce sound castings.

## COORDINATION OF TEMPERATURE GRADIENTS IN MOLD AND METAL

24. Fig. 2 indicates the harnessing of the adverse factors and converts them into favorable factors whereby certain types of steel castings can be made substantially sound by promoting controlled directional solidification.

25. Where, by warrant of the design, it is practicable to apply the total reversal system of mold manipulation,—or even the partial reversal system which will later be expounded—it is definitely advantageous to use hot metal and to pour slowly in order to create the greatest practicable temperature gradient in both mold and metal. The left detail of Fig. 2 shows the casting in the pouring position while the right detail shows the casting after reversal. The inscribed lines as compared with those of Fig. 1*A* and 1*B* may seem to some practical foundrymen to be an over-emphasis of the advantages of the advocated system but the writer is satisfied, after seeing many examples of each type of casting sectioned, that he has not exaggerated in producing Figs. 1 and 2. It is not affirmed that the inscribed lines show with absolute accuracy the progression of solidification, but they do present a fair comparison of what is presumed to occur, such presumption being based upon the examples of sectioned castings produced under the various conditions covered in these sketches.

26. The system of mold manipulation described as "total reversal" has been quoted first to indicate the fullest possible achievement of controlled directional solidification in sand molds without the use of metal chills, but it must be conceded that in the steel foundry the total reversal system is limited in its application by the necessity for additional handling equipment and by the limitation of mold size. A much greater latitude as to size of casting

becomes available when the partial reversal system is employed, and while this system does not present all the advantages of the total reversal system it achieves satisfactory results in a much simpler manner.

27. Maintaining the ingot form for the purpose of illustration, Fig. 3 shows the casting produced on the partial reversal

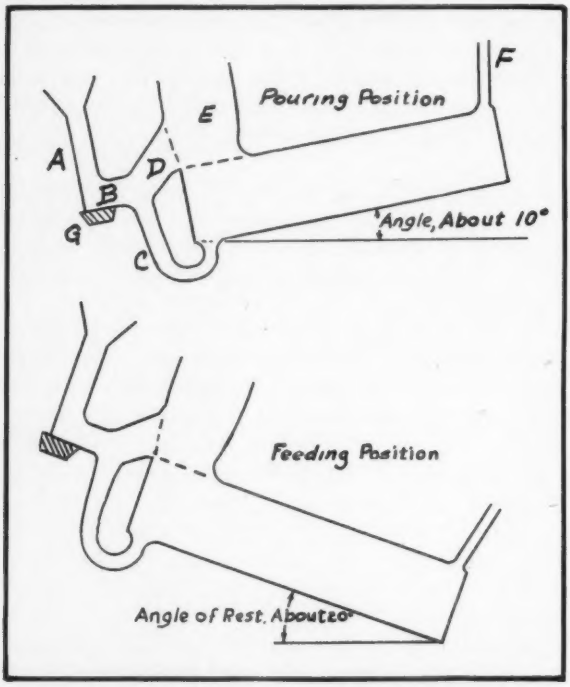


FIG. 3—CASTING PRODUCED BY USE OF PARTIAL REVERSAL METHOD. (*A*) UPPER DOWNGATE; (*B*) CROSSGATE OR BREAKER; (*C*) LOWER DOWNGATE; (*D*) SLOTGATE; (*E*) FEED HEAD; (*F*) VENT; (*G*) SPLASH PLATE.

method. A scrutiny of this figure indicates that, in the pouring position, the lower levels of the mold are progressively heated as the mold is filled while the metal is progressively cooled by transit through the mold. It is not suggested that the first metal which enters the mold is ultimately driven into a position at the upper end of the mold near the vent. It is known that as metal cools in the mold and tends to become sluggish on the surface exposed to the atmosphere in the mold, it may be folded back by the pressure of the more fluid interior metal into contact with the mold face

and form a thin solid envelope. It is affirmed, however, that at the moment the mold is filled, the average temperature of the metal across the section of the casting most remote from the ingate is appreciably less than that of the average temperature of the section of the metal immediately above the in-gates. Also, it is conceivable that between these two extremes there is a fairly regular temperature gradient.

28. The gating system indicated by Fig. 3 is devised to limit the flow of metal through the bottom in-gate and to cause metal to flow through the upper gate which is a slot gate from the cross-gate to the feed head or riser. This provision helps to ensure the

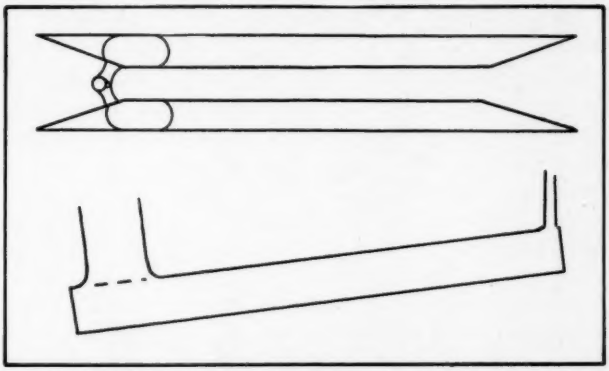

FIG. 4—STRAIGHT BAR CASTINGS PRODUCED BY PARTIAL REVERSAL METHOD.

heating of the riser cavity—that part of the mold which is to contain the feed metal—so that the sand surrounding the head of feed metal will become the hottest part of the mold by the time the casting is completely run and will contain the hottest metal. After the mold is filled the vent is sealed and the mold reversed through an angle of about 30 degrees. A pouring angle of 10 degrees is found to be satisfactory, and reversing through 30 degrees produces an angle of rest of 20 degrees.

29. By such procedure a simple casting of the ingot form may be produced free from axial weakness without an excessive amount of discard as feed head. It should be observed that the procedure achieves the advantages of bottom pouring which admits of the introduction of the metal to the lower levels of the mold without producing undue turbulence such as might result in the destruction of the mold surface and, after reversal, presents a temperature gradient in both mold and metal appreciably more favorable than

could possibly be obtained by top pouring in the vertical position as illustrated on Fig. 1*A*.

30. The next simplest form of casting, after the rectangular ingot section, is an annular form and this ring may be considered, for the purpose of illustration, as consisting of two straight bars of the design shown on Fig. 4. It is obvious that these straight bars could be produced in the manner indicated for the ingot shown on

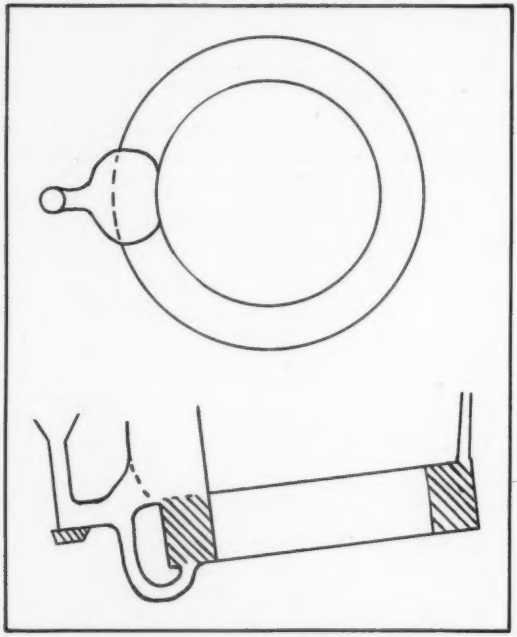

FIG. 5—GATING AND HEADING SYSTEM APPLIED TO RING CASTINGS—CASTING IN POURING POSITION.

Fig. 3, each having its own feed head and being run from a common gate. If the bar shapes are deformed and made to produce a ring one head will feed the whole casting. The temperature gradient in the annular casting will be similar to that produced in the two separate bars provided that metal temperature and pouring rate are equal.

31. The gating and heading system to be applied to ring castings is shown on Fig. 5 and represents a much safer and sounder procedure than is the orthodox tangential in-gate customarily employed in steel foundry practice. With the latter procedure the

number of feed heads increases as the size of the ring increases. With the partial reversal system the size of the single head is, necessarily, related to the size of the casting but, as a general rule, does not exceed 16 per cent of the weight of the annular casting.

32. Fig. 5 indicates the annular casting in the pouring position, the casting being "poured uphill" to promote quiet and clean running, and is reversed through an angle of about 30 degrees after the vent is sealed.

### SIMPLICITY OF THE 30 DEGREE REVERSAL METHOD

33. This system of mold manipulation is quite simple as the mold is located, practically in balance, on a rocking bar or blocks of suitable height. The lower edge of the mold is blocked up to produce an angle of 10 degrees for pouring and the back edge is also blocked up with pieces of approximately twice the height of those under the leading edge, in order to retain the mold in a fixed position until pouring is completed. To reverse the mold, the blocks are removed from the back edge of the mold and the mold rolled into its reversed position, two or three men with short bars usually being sufficient to perform this operation quietly and safely even on molds containing castings weighing as much as one ton. On larger castings the services of a crane may be demanded, but this small additional expenditure of man-time and power is almost insignificant compared with the advantages and economies accruing from the system of mold manipulation.

34. Comparable to the plain annular casting we have a number of other simple types such as crank slabs, heavy base plates, and plain dies of a flat type, which may be made with one head if the width is considerably less than the total length. Where the width is more than half of the length it is advisable to have two risers and gate into each riser.

35. In this latter classification is placed crusher dies, and these are regularly provided with the side riser known to the practical foundryman as a lump head or an elbow head.

36. Following plain castings of the annular or the heavy plate type the next step in complexity is probably best illustrated by the gear blank. This may be either of the plate type or may have spokes. A gear blank casting of the plated type is shown on Fig. 6. In operating this system of mold manipulation on gear blank castings, it is essential to make provision, by means of securing a rocking bar of correct thickness to place under the mold, that the angle of rest will be a definitely known figure. This is considered

essential if the maximum economies are to result from the procedure. The angle of rest will determine the height and volume of metal in the risers, and the rim riser in particular should be of dimensions calculated to hold the requisite or devised amount of metal to feed the rim of the casting after the mold has been reversed.

### TREATMENT OF FEED HEADS

37. Some operators appear to have an inordinate fondness for filling up heads of castings after some considerable shrinkage has taken place, but it is the writer's opinion that such procedure as either unsound or almost worthless as applied to the range of

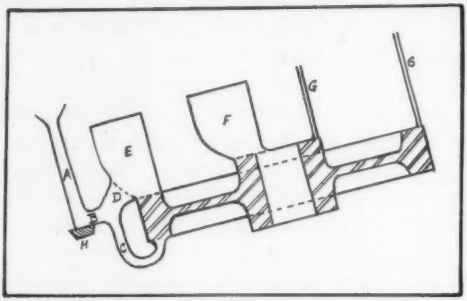


FIG. 6—GEAR BLANK CASTING OF THE PLATED TYPE IN POURING POSITION. (*A*) DOWNGATE; (*B*) CROSSGATE OR BREAKER; (*C*) HORNGATE, PRODUCED IN A CORE; (*D*) SLOTGATE; (*E*) HEAD ON RIM; (*F*) HEAD ON HUB; (*G*) VENT; (*H*) SPLASH PLATE.

medium weight castings between 500 and 2000 pounds each. Particularly is this the case when orthodox gating procedure is followed as the heads imposed on such castings almost invariably show such an elongated contraction cavity that if much feeding has been done the upper levels of metal in the feed head are so cool when the heads are filled up with hot metal that they promote almost immediate freezing of the upper levels of the additional metal poured into the heads. The repeated feeding of the heads of very large castings is entirely another matter as the conditions are considerably different. The writer's preference in the making of small and medium weight castings is to have the riser cavities of such size that they will contain all the metal essential to complete feeding when filled up to within one inch of the top at the time of pouring, and the surface immediately covered with an insulating powder of one of the well-known types.

38. It is inadvisable to fill risers right up to the surface level of the top of the mold as this prevents covering the top of the

cast metal with a sufficient thickness of material to serve as an insulator. Metal exposed to the atmosphere appears to lose its heat even more quickly to the atmosphere than it does to the mold with which it is in contact. When this occurs at the surface of a riser or feed head an appreciable proportion of what should be feed metal is immobilized by surface solidification.

## TEMPERATURE GRADIENTS RELATED TO PROPORTION OF FEEDER HEADS

39. The proportion of feed metal which has to be applied to gear blanks is a variable, but it has been found that feed metal ap-

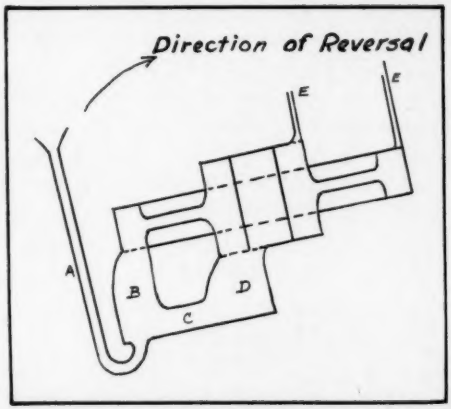


FIG. 7—METHOD OF PRODUCING GEAR BLANK CASTING WITH SMALLER PROPORTION OF FEED METAL AT THE HUB AS CONTRASTER TO METHOD OF FIG. 6. (*A*) DOWNGATE; (*B*) RIM HEAD; (*C*) CROSS GATE, CONNECTING *B* AND *D*; (*D*) HUB HEAD; (*E*) VENT.

plied to the rim is adequate when it is equal in volume to between 16 and 20 per cent of the volume of the rim plus spokes or plate. The volume of the riser imposed on the hub varies with the interrelated dimensions of the hub. The proportion applied to the hub is necessarily greater than the proportion applied to the rim because the metal which fills the hub riser has been cooled in transit through the mold and is superimposed on metal a little hotter than itself. In the hub and hub riser there is an adverse temperature gradient, therefore it is necessary to have a hub riser of a size which appears disproportionate as compared with the riser imposed on the rim. As a general rule the riser on the hub is devised to have a capacity of between 35 and 50 per cent of the volume of the hub.

40. It is possible to produce gear blanks with a smaller pro-

portion of feed metal at the hub and the procedure for this is indicated by Fig. 7, which shows a connecting gate between the rim riser and the hub riser and also involves the reversal of the mold through an angle of 180 degrees. It is sufficient to say that a number of years of practical experience have proved that only in very rare instances is it worth while to go to the total reversal system for the production of gear blanks, the partial reversal system having been found adequate and appreciably simpler in almost every instance.

41. Gear blanks provide an excellent opportunity of inves-

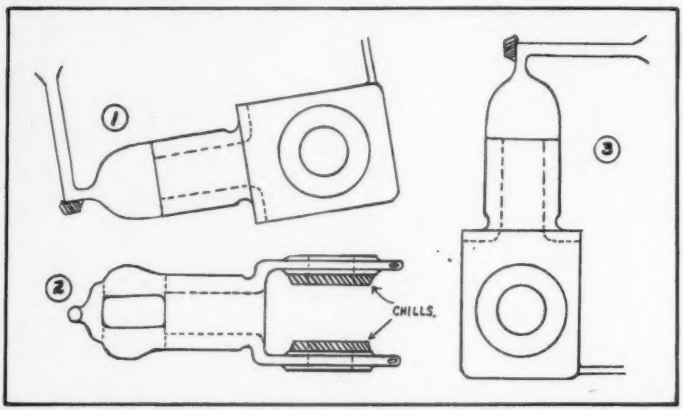


FIG. 8—METHOD FOR PRODUCING CROSSHEAD CASTING OF CONVENTIONAL DESIGN. (1, UPPER LEFT) MOLD AT ANGLE OF 10 DEGREES FOR POURING; (2, LOWER LEFT) PLAN VIEW SHOWING TWO INTERCONNECTED HEADS AND CHILLS IN POSITION; (3, RIGHT) CASTING IN FULLY REVERSED POSITION.

tigating the efficiency of this system of gating and heading which promotes controlled directional solidification. In the majority of cases the cutting of the teeth of a gear results in the exploration of the cast section to a depth well below the mid-section of the rim, and it has been the experience of the writer that it is consistently easier to produce gears which show no sign of structural weakness at or near the center of the rim section when the pouring system is devised to achieve controlled directional solidification, than when the more orthodox system of gating and heading is employed which demands either extravagant heading or involves some serious risk of at least slight unsoundness being revealed upon the cutting of the teeth.

42. A single example will be shown of the system that lies between the total (180 degree) reversal and the partial (30 degree)

reversal systems. This is known as the 100 degree reversal method. The example selected is also of interest because external chilling is employed at relatively heavy sections remote from the in-gate.

43. Fig. 8 shows a cross-head of conventional design, and the details of the figure are almost self-explanatory. The chills are of semi-annular shape and are mounted in the core, in preference to being located in the mold, for the reason that as the casting contracts it will remain in contact with the chills in the core whereas it would tend to contract away from chills imposed in the mold.

44. The mold is located at an angle of 10 degrees for pouring, as shown in the upper detail of the figure, and after pouring is completed the vent is sealed and the mold reversed through an angle of 30 degrees. It is allowed to rest in this position for a short time, probably 10 to 15 seconds, and the reversal through a further 70 degrees is then made. Detail 2 of the Fig. 8 shows a plan view of the casting with two inter-connected heads, and the chills in position. Detail 3 of Fig. 8 shows the casting in its fully reversed position and it will be seen that the feed heads are in the ideal position to permit gravitation to augment the considerable temperature gradient which has been created, in a favorable direction, in both mold and metal.

## CREATION OF A STEEP TEMPERATURE GRADIENT

45. In all the foregoing examples it is the practice of the writer to use metal as hot as is practicable and to pour as slowly as is consistent with the observed temperature and fluidity of the metal. These provisions are devised to create the greatest possible temperature gradient, within the governing conditions at the time, possible in both mold and metal. Admittedly high temperature metal and slow pouring would be wrong in most instances, even dangerous, under conditions of orthodox gating and heading procedure.

46. Some objections may be raised to the apparent evasiveness of the use of the word "practicable" in describing the metal temperature and pouring speed. The limit of this practicability is principally related to the effect of metal upon molding sand or other molding materials which produce the gate or gates and those parts of the mold closely adjacent to the in-gate or in-gates. High temperature metal or metal rushing into a mold at high velocity tend to promote defects in steel castings if the molding materials are not thoroughly competent to withstand the thermal and physical attacks of the metal.

47. In order to secure the advantages made available by mold manipulation in association with hot metal and slow pouring it has been necessary to make some modification of molding materials. Briefly, provision has been made to avoid erosion of the gates and the parts of the mold closely adjacent to the gates by providing gates cores and insert cores for the mold of a special nature. Particulars of these cores are given in another paper[2] submitted by the writer at the presentation of the Symposium on Porosity in Steel Castings at this convention. By the use of such materials the range of practicability of high temperature and slow pouring speed is augmented considerably above what is available in terms of orthodox practice. This particularly applies when skin dried molds or green sand molds are used. Within the past few years many castings of a type and size which previously were considered safe only in dry sand molds have been made in green sand molds with special gate cores and core inserts. Dies up to 5000 pounds in weight, some having massive sections, have also been made in the same manner.

48. By ensuring that the parts of the mold closely adjacent to the in-gate are competent to resist the attack of hot metal a pouring speed becomes practicable which, permitting an adequate rate of flow in the mold, does not impose any excessively high temperature upon any part of the mold except the parts close to the in-gate.

49. When castings of approximately uniform section are shaken from the mold it is often possible to clear the sand easily from the exterior surfaces. In many instances it is easy to observe a marked difference between the temperature of the casting near the in-gate and the temperature at parts of the casting remote from the in-gate. Between these two extremes there is, if the metal section is uniform, a smooth temperature gradient.

## ADVERSE TEMPERATURE GRADIENTS AND INTERNAL WEAKNESS

50. If the casting is provided with risers, relatively remote from the in-gate, the parts of the casting adjacent to the risers will show a higher temperature than other parts of the casting which lie between the risers and the in-gate. Such a condition is not conducive to the production of absolutely sound steel castings and the writer feels that uniform-section castings, made on lines of orthodox practice, may be more afflicted with fine cavities, located at the mid-thickness of the section, than has been generally suspected.

[2] *"The Relation of Molds and Cores to Porosity in Steel Castings."* A. F. A. Preprint 34-25 (1934).

Such metallurgical defects may not have represented commercial deficiency in the majority of steel castings, but when once a cavity has been convicted as the culprit in a failed casting, all cavities become suspect.

51. There seems to be no reason to dispute the assertion that no matter how satisfactory a casting may be in service even though it contains one or more fine contraction cavities, it would still be a safer casting if it contained no such cavities.

52. No doubt it could be proved by gamma ray or x-ray ingation that steel castings which have given a full life of satisfactory service were afflicted with defects of a type and size that might now lead to rejection, but this proves nothing except that radiographic examination of castings reveals deficiencies or proclaims soundness by a non-destructive method.

## SOME DESIGNS INVOLVE DIFFICULTIES

53. It must be recognized that enclosed shrinkage cavities, tending to develop hot cracks, are potential sources of failure and should, if possible, be eliminated where the demands of service are such that commercial and metallurgical perfection are synonymous.

54. By a system of heading, gating, or mold manipulation it is found practicable to create temperature gradients in both metal and mold which promote controlled directional solidification in castings of relatively simple or uniform design. As the complexity of a casting increases by reason of marked differences of section thickness the facility with which controlled directional solidification may be promoted tends to decrease. Some designs are of such a nature as to make it impossible to produce a sound steel casting of the predicated dimensions but, happily, designers are now affording founders more opportunities for collaboration.

55. It is obviously impossible to have all steel castings designed so as to produce tapering sections of the "big end up" type although much might be done, for certain types of castings, by applying the principle advocated by Heuvers as cited by Briggs and Gezelius.

56. It has been shown that controlled directional solidification may be attained in certain types of castings without the use of chills, but it must be admitted that the types represented by the examples already discussed are really of simple design. Practical foundrymen know that some of these simple shapes, such as gear blanks and brake drums, are either difficult or expensive to produce as compared with many other castings of more intricate de-

sign. This may be related to the fact that such castings of simple form as gear blanks and brake drums are very considerably explored by machining operations while some of the other castings of more complex design may be machined only on a few isolated pads or bosses.

### FAILURES MAY BE RELATED TO DESIGN

57. Castings which have to meet service conditions involving high pressures at either normal or elevated temperatures, or castings which must withstand repeated alternations of stress should be as sound as possible. Failures in service have been attributed to internal hot tears and shrinkage cavities generated in the casting as a result of incomplete feeding of a heavy section. This failure to feed the heavy section may have been the fault of the founder, or the design may have been such that it was impossible to deliver the requisite amount of feed metal.

58. Briggs and Gezelius, in their paper previously mentioned, state: "A plan of solidification involving controlled directional feeding is especially adaptable as it employs the methods that are involved in the regular solidification of a steel casting. And it does more, it does not permit sections to solidify heterogeneously throughout the casting, but controls the direction of solidification so that adequate reservoirs of liquid metal will feed the last solidifying portions. The authors are of the opinion that in order to obtain castings free from pipes and voids it is necessary to have controlled directional solidification taking place within the casting."

59. With such a statement the writer fully agrees, but would insist that there is a limit beyond which the designer should not go in disposing isolated heavy lumps or sections on a relatively light general structure in such locations as make it almost impossible, even with all the artifices of gating, heading, chilling and mold manipulation, to ensure the internal and superficial soundness of the casting.

### CHILLS, INTERNAL AND EXTERNAL

60. The use of chills to absorb the heat of heavy sections which cannot conveniently be fed by risers is fairly common practice but there is, as yet, no accurate published information as to the relation of size of chill to the size of the part with which it contacts. Internal or "cast-in" chills will not here be discussed at any length as the writer considers them, except when they are

subsequently removed by machining, potentially dangerous as isolated foreign bodies in what should be a homogeneous structure.

61. External chills are much more expensive to produce and apply than are internal chills, but they are much more satisfactory in the majority of cases. In the chilling of a casting to promote controlled directional solidification it is necessary to use chill blocks of proper shape and size. The weight of the chill must be properly related to that portion of the casting upon which the pad, boss, or thickened section is imposed. In some instances, it is necessary to have the chills of tapering section—as the walls of ingot molds are tapered—to ensure the correct progress of solidification.

62. If a chill is too heavy it may defeat its own devised object and, by cutting off the supply of feed metal, promote unsoundness in other parts of the casting. An example of this kind came to the writer's notice only a short time ago and it is considered politic to sound a note of warning against the use of chills without securing, by experimentation, some knowledge of their behavior. It has been stated flippantly that the art of making steel castings largely consisted in putting the holes where they would not be found. If that was ever true, the art is no longer of value. Chills must be so devised and applied as to promote soundness in the cast structure. If they only alter the location of internal defects, even though they decrease the size of the defects, they are not fully efficient.

63. A factor which affects the efficacy of external chills is the amount of metal which is passed over them in the pouring operation. The size of a chill must be related to the heating to which it is subjected while the metal is in motion in the mold as well as to the mass of metal at rest with which it contacts.

## POURING TEMPERATURE AND POURING DESIGN

64. Pouring temperature is a distinctly debatable question, and Briggs and Gezelius aligned themselves with a very small minority when they stated: "Pouring from elevated temperatures as a means to avoid hot tears probably sounds like a foolish suggestion to most experienced steel foundrymen whose slogan for years has been 'Pour her cold and prevent cracking.' This opinion is urgently in need of correction." The writer is one of the minority holding the belief that too much virtue is attributed to low pouring temperature, but also it should be noted that he does not subscribe to a blanket prescription of hot pouring.

65. In some types of casting it is possible to assist materially

in promoting controlled directional solidification by using hot metal which admits of filling the mold relatively slowly. This applies to molds which are not manipulated in the "reversal" system.

66. An example is shown on Fig. 9 of a light steel casting which, when poured with metal of average or normal temperature

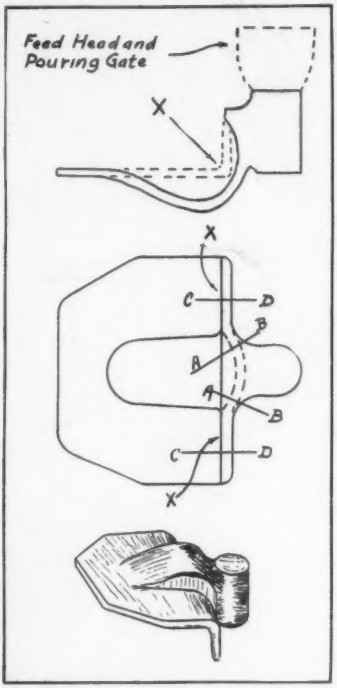


FIG. 9—AN EXAMPLE OF A CASTING WHICH, WHEN POURED WITH AVERAGE TEMPERATURE METAL, EXHIBITED SURFACE TEARS. TEARS WERE ELIMINATED BY SLOW POURING WITH HOTTER METAL.

exhibited surface tears in the radius at the places marked *X-X*. These external tears were, as frequently occurs, evidence of an internal shrinkage cavity and sectioned castings showed a fine internal defect in one or two cases when no external tear was apparent.

67. The section thickness at *A-B* is lighter than that at *C-D*, but the pattern could not be altered to remove this obvious deficiency. Instead of using chills to promote soundness at the affected places—and possibly drive the defect to another location—some of

the hottest metal from each heat was used to produce these castings and slow pouring was insisted upon. By pouring slowly with hot metal the parts of the mold which formed the necks *A-B* were appreciably heated by metal in transit and, consequently, these avenues of feed metal remained open a sufficient length of time to ensure the soundness of the casting.

68. The foregoing is not an isolated example, but is typical of a number of other cases wherein variations from the orthodox "pour cold" has resulted in marked improvement of product.

## GATING SYSTEMS AND MOLDING MATERIALS

69. With most of the conventional molding materials it is not practicable to use the top-pouring method for steel castings except in the case of really heavy pieces of large size and massive section. Bottom-gating of sand molds is almost general practice and has the warrant of cleanliness. It must be admitted, however, that bottom-gating tends to promote the adverse temperature gradient in both mold and metal which is inimical to internal soundness. To minimize this adverse temperature gradient a system of step-gating is used by some foundrymen on castings which are of considerable height.

70. Temperature gradient must not be considered as existing simply in the vertical plane because of the orthodox system of gating at the bottom and heading at the top. In many light steel castings of a generally flat or shallow type a perfectly satisfactory temperature gradient in the horizontal plane is produced by orthodox procedure where the pouring gate is the only reservoir of feed metal.

71. Gating is considered particularly important and a great deal more attention could profitably be given to the location, size, and delivery angle of in-gates, and to the use of "breaker" gates in conjunction with step-gates to promote better temperature conditions in both mold and metal.

72. As a general principle it is sound to gate into the heaviest available section of a casting and to dispose this heavy section, in the molding operation, in such a position that it may carry the major feed head. It is recognized, of course, that many castings require several feed heads, but the prime principle of controlled directional solidification is to a great extent related to the close proximity of main feed head to main in-gate.

ACKNOWLEDGMENT

73. The author records his thanks to the American Society of Naval Engineers for permission to use certain illustrations which were published in the Journal of the Society in February and August, 1934.

## DISCUSSION

C. W. BRIGGS[1] AND R. A. GEZELIUS,[2] (*Submitted in Written Form*): We sincerely hope that the practical foundrymen appreciate this paper as much as we do. We congratulate Mr. Batty on the clear and concise manner in which he presented the practical application of controlled directional solidification.

As the author has pointed out the idea of directional solidification is not new. However, the application of the principal seems to be little used. Mr. Batty's method of mold reversal is unique and fulfills nicely the requirements of directional solidification and the logic behind Mr. Batty's manipulation can undoubtedly be seen by everyone.

An interesting point on which the author touched, and on which he appears to be collecting data, is the relation of the volume of the riser to the volume of the section being fed. This is a point on which considerable study could be made with all practical foundrymen contributing since from the resulting symposium a set of generalized rules probably could be devised that would be of real value.

We are especially grateful for Mr. Batty's discussion on the practice of slow pouring high temperature metal. There has been considerable misinterpretation of this point. We feel that the confusion on this subject is a primarily one of not recognizing certain mold conditions. A certain foundryman discussing the point of fast pouring at a recent meeting of a technical society stated that it was absolutely necessary to use as fast a pouring speed as possible since slow pouring and high temperature metal would cause defective castings. He went on to explain that the defective castings resulted from the mold falling in, because of its inability to withstand the reflected heat. In this case, the primary fault was with the molding sand and not wtih the method of pouring. There are molding sands that will withstand the conditions of high temperature and slow pouring, thereby allowing the method to be adjudged on its own merits alone. Surely this is a more logical way of studying conditions.

CHAIRMAN R. A. BULL: Mr. Batty's paper relates to the stress under which the steel foundryman labors in applying ingenuity to make a good job out of a piece of metal designed in a way to present metallurgical difficulties. Throughout all of my consideration of this interesting method, I have been impressed by its usefulness for a great many castings, and what you might call, its development and refinement of a method in the

[1, 2] Division of Physical Metallurgy, U. S. Naval Research Laboratory, Washington, D. C.

same general direction applied probably 25 or 30 years ago (or perhaps longer), in this country, by the tilting of certain flasks immediately after they were poured, to accomplish in part the same effect.

JOHN HOWE HALL[3]: There are one or two things in the paper that I want to, if not take exception to, at least question. In Paragraph 9, Mr. Batty speaks of Mr. Brearley's introduction of the tappered ingot mold producing an ingot of appreciably greater area at the top than at the base. I do not remember when Brearley wrote about that, but I do remember very well indeed when Howe and Stoughton, in 1907, published in the proceedings of the American Institute of Mining and Metallurgical Engineers, the results of a really profound study of ingot pouring practice. As some of you may remember, they worked with stearine, which is another word for beef tallow. They studied at great length the effect of pouring an ingot with the big end at the top and the little end at the bottom, and filling a mold from the bottom and from the top and filling it slowly and filling it rapidly, etc. It was really the first comprehensive study of just what Mr. Batty is talking about and what I think, unfortunately, he calls controlled directional solidification. That is a mouthful of words for most of us. I really question whether it is not Howe and Stoughton who first pointed out the advantage in freezing steel, of having it freeze from the bottom first and the top feed it. Emil Gathman took Howe and Stoughton's idea and put it to work, about 1909, if not earlier. Today, practically every ingot of high grade forging steel in the United States is from a Gathman mold, the design of which is based on the researches of Howe and Stoughton.

It is very, very interesting to see the clever way in which Mr. Batty has taken advantage of the idea of getting the hottest metal and the hottest mold at the top, where you want it, by turning the mold upside down. I see some men in the room here to whom that is an interesting abstraction but not a particularly valuable idea, because some of their molds are so big that nothing will turn them upside down. In my particular line of foundry work, the idea is of extreme value. I believe in a great many cases you can produce the same result equally well, especially in cases of deep molds, by gating at two, three, or four, levels. That is an idea I discussed at some length in a paper* before this society in 1914 By that method, I pointed out, the cold metal is at the bottom and the hot metal at the top. I will admit, though, that until I heard of Mr. Batty's reversal method, my mind had not grasped the importance of having both the hottest metal and the hottest *mold* at the top.

There is another point on which I think Mr. Batty deserves to be emphatically complimented, and that is where he pays his respects to an improperly made horn gate; if not properly made, it is the worst thing you can possibly have.

There is one advantage in Mr. Batty's method that I do not see that he has pointed out. He pours uphill on a comparatively flat casting, and pouring uphill gives a little better opportunity for any dirt and slag, that

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[3] Taylor Wharton Iron and Steel Co., Highbridge, N. J.

* *"Defects in Steel Castings and How to Remedy Them"*—TRANS. A.F.A., vol. 23, pp. 537-573, (1914).

may be on top of the steel, to slide along the cope and get to the head, than if you pour in a horizontal position. I almost question whether his 10 degree angle, from that point of view, could not be advantageously increased to a higher angle.

In the illustrations in the paper, there is one thing I do not understand. In Figs. 3 and 8 there is a cross-hatched piece right at the bottom of the down gate; in the upper sketch of Fig. 3, it is at the bottom of the part marked 8, and in the other picture it is at a similar location.

MR. BATTY: That is a splash plate, to avoid mold erosion.

MR. HALL: Of course it does avoid mold erosion, but to some extent it counteracts the effect that he is trying to get of having the hottest metal go up into the head.

F. A. MELMOTH[4]: I was very much interested in Mr. Hall's description of the work carried out in this country in the early days on the large end ingot. I have been fortunate in that I was working under Mr. Harry Brearley's direction at the time when he was doing some of this work and earlier work was described to me by his brother, Mr. Arthur Brearley. Wide end ingots cast from the bottom, with hot tops, were used in the steel works in which I started 30 years ago. Mr. Harry Brearley at that time was carrying out experiments with stearine wax in the laboratory of Thomas Firth & Son on the influence of shape on ingots. Now I do not think there is any question of professional priority in that, it just happened that it obviously coincided with the work carried on over here by equally prominent men. As to the practical value of this paper, which is all that interests us, I have been in this from, I think, its inception. With Mr. Batty present, I believe, I saw the first mold which was treated in this particular way. It might be valuable to say that long after my connection with Mr. Batty in business had ceased, we were making hundreds of tons of castings applying these very methods, hundreds of tons, not just a few. Those castings ranged from around 50 lbs. up to a maximum of several tons. On one occasion, I have seen castings weighing 3 tons given a complete reversal. Frankly, I did not like it, it was too dangerous, but it certainly produced the castings. Some of these castings gave as high as 92 per cent yield of saleable castings and were perfectly sound; the average would run from 67 to 90 per cent of saleable castings from the metal poured. These data are the results of careful weighing, so there is no question about the practical application of this particular idea.

Another thing that obviates all possible criticism of this method, is that it is entirely logical. We know that most of our castings are made in such a fashion that we have an utterly incorrect relation between the metal temperature and the mold temperature and this is the only way to bring the correct conditions about, as far as I can see.

CHAIRMAN BULL: Obviously this method is much more applicable to the operation of small steel casting plants which generally use the electric furnace than to the large open hearth plants. Mr. Melmoth's reference to one large casting must have prompted some people to feel that the method

[4] Detroit Steel Casting Co., Detroit, Mich.

has applicability to moderate sized castings which perhaps they did not previously think of as belonging in that selected category.

E. W. PIKE[5]: Mr. Batty was with our company for a time, and during that period he introduced some of these methods. Since then, we have employed the partial and complete reversal method on a number of types of castings to very decided advantage; advantage in yield, advantage in solidity, and advantage in cleanliness of the type of casting we made. The method, in my judgment, is not very applicable to small castings, but is particularly applicable to medium sized castings, made in metal flasks. It is applied to that type of castings in our plant. There are a number of instances where it is difficult to get good castings except by such a method. I have in mind one particular type of crankshaft that we make for one of our customers. We tried it a number of times by the so-called orthodox method, without success, but by putting our risers on the bottom, and applying our gate to the riser at the top of the crankshaft and turning the flask completely around after pouring, we had great success, and through a number of years we have been making that particular casting in that way.

MR. BATTY: This paper was written with the particular point of view of showing practical foundrymen what has already been done in achieving soundness in steel castings by the adoption of procedure that promotes the controlled directional solidification which Messrs. Briggs and Gezelius stressed so strongly as a desirable principle in the first of their series of papers in their studies of steel castings.

My present paper has treated the production of steel castings in molds which are manipulated by rocking or reversing after pouring is completed, but I am well assured that the gating and heading systems—that is, the positional inter-relation of gates and heads—in the reversal method of casting production, indicate principles which must be valuable in the production of castings in unmanipulatable molds, molds that cannot be rocked.

We have an example of such sound gating and heading procedure presented to us in the British Exchange paper. In the admirably illustrative diagrams submitted in that paper, it will be seen that the ingates deliver metal to the roots of two major feed heads so that throughout a considerable proportion of the casting an adverse temperature gradient is avoided.

In operating the method of promoting controlled directional solidification in manipulated molds, it has definitely been my practice to use metal as hot as is practicable and to pour as slowly as is practicable. This has involved the introduction of certain modifications of molding materials and in the presentation of the paper I may not have stressed this point sufficiently strong because throughout a number of years this detail in reference to special molding materials has become a commonplace factor of the method. Mr. Gezelius has referred to this point and it is undoubtedly due to the meeting that proper emphasis should be placed upon the provision of mold surface material for gates and for the part of the mold closely adjacent to the ingates—which includes also the head cavity

[5] Detroit Steel Casting Co., Detroit, Mich.

—competent to withstand the abnormal thermal and physical attacks of the metal.

Now with regard to what Mr. Hall has said in reference to the work of Messrs. Howe and Stoughton in 1907, I would say that it was in that particular year I conceived the idea of using tapered molds for the production of crucible steel ingots. At that time, I was very young and very susceptible to injury. It was occasionally my job to hold ingots on the anvil to be "topped" and when such ingots piped below the "dozzle" or hot top the fellow who held the ingot on the anvil was liable to some severe shock. The pain of experience led me to the necessity for inventing a cure for the trouble and I conceived the idea of the tapered mold, big end up, which would permit of the application of a larger feed head or "dozzle." You will realize that at the time I had no conception of controlled directional solidification. I took the proposition down to discuss with a firm of ingot mold makers in Sheffield and the two courteous gentlemen, George and William Oxley, listened patiently to my exposition of what I hoped to achieve by the modified mold design. When I had finished they told me that they were perfectly sure the idea was sound and practicable because they had been making molds of such design for Mr. Harry Brearley for about 15 years.

This illustrates the kind of thing which must have happened many many times and it also serves to indicate the fact that something which is hailed as a scientific discovery has been operative in production for quite a long time. While I have no desire to deprecate the work of Howe and Stoughton, nor the frequent reference in this country to the Gathman mold, I feel it proper to state that the practical genius of Brearley was being applied in the production of sound steel ingots at a date much earlier than that proclaimed in this country as the advent of sound ingot production. Despite the shock of finding that my ideas of the subject had been anticipated, I feel able definitely to affirm that Sheffield, England, was the birthplace of the correctly designed ingot.

MR. HALL: Was this information published?

MR. BATTY: No, but they had been using the molds of the big end up type for approximately 15 years previous to 1907. I make this statement on the authority of Mr. George Oxley as quoted previously.

With regard to step gating, as Mr. Hall has suggested, to avoid an adverse temperature gradient in the metal I would say that this is quite sound practice on castings which are of considerable vertical height in the pouring position. It should be stated, however, that simple step gates from a straight vertical downgate will not achieve the desired result. The velocity of the vertically flowing metal would not permit the simple step gates carried at an angle from the vertical downgate to function properly. Step gating can only be made to function properly if every step is taken from the end of a horizontal breaker gate. The downgate, therefore, in a properly gated mold may take the form of a flight of stairs and such procedure is easily accomplished by the use of properly made core gates which are rammed up in position in the molding operation. I have found it essential, in step gating large castings, to avoid acute

hot spots at the junction of the step gate with the castings by producing small lump or elbow heads as the actual ingate.

With reference to Mr. Hall's comments on the angle of pouring, that is the amount of "bank," this must necessarily be related to the height of the head which it is possible to impose on the casting, unless a blind head is employed. This comment refers particularly to castings made on the partial reversal method and Mr. Hall is quite right when he insists that the greater the angle of bank, the cleaner the casting is likely to be. With a blind head, all that is necessary to ensure the complete running of the casting is that the downgate should be built up to a height adequate to ensure the requisite amount of ferro-static pressure to drive the metal to the remote end or parts of the mold.

The effect of the splash plate on the cast metal is purely relative; a splash plate weighing only one lb. is adequate in most cases at the base of a gate of a casting weighing as much as 1000 lbs. and I do not think that there is much danger of seriously affecting the temperature gradient of the metal within the mold by the use of such a splash plate.

Concerning Mr. Pike's discussion, I would say that the articles published in the Journal of the American Society of Naval Engineers gives a number of interesting illustrations of what has been done with certain types of castings, although the particular crankshaft to which Mr. Pike referred is not therein discussed or illustrated. It may be said, however, that the brake drum illustrated in one of those articles was produced in Mr. Pike's foundry.

I cannot agree with Mr. Pike when he expresses the view that the reversal method of mold manipulation is chiefly applicable to medium weight castings. It is almost astounding what can be done in the way of achieving economies on quite small castings by a proper system of heading and gating, with or without mold manipulation. At the same time I am prepared to insist again that what we learn from the system of heading and gating which is applied to manipulatable molds must lead us to a more correct conception of the proper methods of gating and heading to be applied to large castings which are made in holes in the ground and in large mold and core assemblies. It must not be forgotten, also, that chilling and mold relieving must be studied with a view to their application in the production of larger castings in either manipulated or unmanipulated molds.

I would not like this meeting to take away the idea that this method of casting production which I have today expounded is my own particular original conception. The steel castings industry is one which is competent to keep a man reasonably humble and while I am reasonably proud of my achievements in producing sounder, better and cheaper castings on the methods today expounded, I wish to state the methods I have evolved are definitely the outcome of two things which I observed in the foundry of Messrs. Lake & Elliott at Braintree, England, in 1922. The first of these was the gating method devised by a sound old practical foundryman, Mr. Harry Langley, for the production of half gear blanks. This was modified slightly by F. A. Melmoth who was in charge of that foundry and later Mr. Melmoth stated to me that he believed it possible

to produce annular castings with only one feed head. This latter project was tried out but, for some reason which I do not remember, was not particularly successful. The germs of these two ideas remained in my memory and, some two or three years later, provided the solution for certain defects experienced in the production of certain types of castings. Once the principle was established by repeated experiments, the thing has gradually and steadily evolved until it is now applied to a great many types of castings. I was happy to be able to return to Mr. Melmoth his original idea worked out into the very simple partial reversal method and also to carry the thing further to the total reversal method. Mr. Melmoth has now told you how he has applied the total reversal method to very much larger castings than I had attempted to produce on such a system.

You will therefore please understand that I make no claim to be the originator of the idea of mold manipulation as a fundamental in promoting controlled directional solidification but that I developed the original conception of two different men in my endeavors to produce sounder, better and cheaper steel castings.

# Modern Equipment Used in Crucible Melting

By Richard H. Stone,* Swissvale, Pa.

**Abstract**

*Crucible melting recently has received an impetus due to the adoption of fuels not generally used previously, to better refractories, greater crucible life and new furnace design, according to the author. By basing the economy of a fuel on the cost of a million heat units actually utilized, the author compares the costs of the various fuels available. He also outlines difficulties encountered with various fuels and how to overcome them and describes some new type installations which are giving good results. In discussing refractories for crucible installations, he gives instructions on the care of furnaces that will improve melting conditions and lengthen crucible life. He also describes several special crucible furnaces that are being widely adopted and outlines the advantages of several typical installations. At the end of the paper, a chart is given which analyzes the operating costs of modern crucible plants.*

1. While the simple crucible method of melting is one of the oldest, improvements and changes have been found necessary to meet the requirements of new fuels or fuels that have not hitherto been generally used for this purpose. Likewise, development of refractories has influenced furnace design and there are a few instances of furnaces newly designed for melting certain metals in crucibles.

2. Consequently, this paper has been divided into sections under the following headings: (1), fuels and burners; (2), furnace refractories; (3), crucibles; (4), special furnaces; (5), typical modern installations of crucible furnaces, and (6), melting costs.

## Compares Fuels.

3. In addition to coke and coal, natural and artificial gases, fuel oil and electricity are now all widely used as fuels, some of

* Chemical Engineer, Vesuvius Crucible Co.

Note: This paper was presented at a session on Refractories at the 1934 Convention of A. F. A.

them being cheaper than coke and more particularly anthracite coal. All of them are preferable to solid fuels on account of ease of handling and clealiness.

4. It is interesting to compare the various fuels as to cost per thermal energy unit. Table 1 gives the cost for one million heat units for each fuel and, allowing for the efficiency with which each fuel is used, the cost for one million B.t.u. actually utilized.

**Table 1**

COST ANALYSIS OF VARIOUS FUELS USED IN CRUCIBLE MELTING.

| Fuel | Price | Cost per Million B.t.u. | Efficiency % | Net cost per Million B.t.u. |
|---|---|---|---|---|
| Electricity | $0.02 per KWH. | $6.00 | 40 | $15.00 |
| " | " | | 90 | 6.66 |
| City Gas (manufactured) | $1.15 per M. cu.ft. 540 B.t.u. per cu.ft. | 2.13 | 15 | 14.20 |
| Natural Gas | $0.50 per M. cu.ft. 1000 B.t.u. per cu.ft. | 0.50 | 10 | 5.00 |
| Fuel Oil | $.04 per gal. 140,000 B.t.u. per gal. | 0.29 | 10 | 2.90 |
| Coal Anthracite | $12.00 per ton 12,000 B.t.u. per lb. | 0.50 | 5 | 10.00 |
| Coke | $5.00 per ton 13,000 B.t.u. per lb. | 0.19 | 5 | 3.80 |

5. Fuel oil of 28-30 degree Bé gravity may be obtained in tank car lots at as low as $0.04 per gal. and, with a fuel consumption of 35 gals. per ton melting red brass, the fuel cost figures only $1.40 per ton of metal melted.

6. The use of fuel oil requires some special provisions and attention. When oil first began to gain in application in foundries using crucible furnaces, the life of crucibles was very irregular and, on the average, lower than with other fuels. As similar difficulties in connection with the application of natural gas had been encountered several years before and had been overcome, it was apparent that, with study, fuel oil could be made just as suitable for crucible furnaces as natural gas.

7. The trouble was attributable to several defects, all of which come under faulty combustion. Atomization was imperfect; there were pulsations in the oil line; too much secondary air was admitted; insufficient space was allowed for liberation of the heat

from the burning mixture of oil and air. Happily, the present crucible furnaces designed for oil fuel eliminate these difficulties or have greatly improved the conditions. Crucibles frequently give a hundred heats or better with oil fuel in either pull-out or tilting type furnaces melting red or yellow brass. Fig. 1 shows a typical installation for oil-fired crucible melting.

8. Atomization may be accomplished with oil pressures of 30 to 50 lbs. and air at 18 oz. Under these conditions and with any one of a half dozen or more types of burners, very good combustion conditions and good economy may be achieved. Pulsation and interruption in oil feed may be eliminated largely by the use of

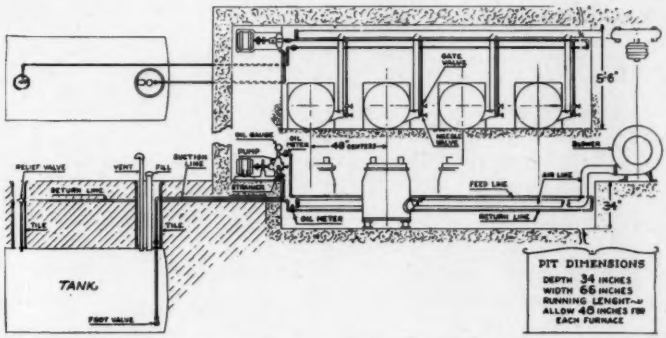


FIG. 1—DIAGRAMMATIC LAY-OUT OF COMPLETE OIL BURNING, CRUCIBLE FURNACE INSTALLATION. (*Courtesy Fisher Furnace Company, Chicago, Ill.*)

proper sedimentation of the oil in storage and introduction of strainers in the line. Secondary air introduced around the nozzle is highly undesirable, if the other equipment is properly designed. It has been found that, if twice the theoretical amount of air for complete combustion is introduced, the flame temperature is reduced by half. Thus, flame temperature of combustion of carbon to carbon dioxide ($CO_2$) with only the theoretical amount of air supplied is 4952 degrees Fahr.: with twice the amount of air the flame temperature is only 2283 degrees Fahr.

9. If the burner is located too close to the crucible, combustion is only partially completed by the time the flame hits the crucible and the maximum flame temperature will be reached somewhere near the top of the furnace. Under these circumstances, the flame may be so cold at the bottom of the furnace that solid carbon will deposit on the bottom of the crucible while the tem-

perature at the top may be sufficient to melt copper. Not even a graphite crucible, with its high heat conductivity, can long withstand such an unequal temperature distribution. The remedy lies in attaching an ample combustion chamber or tube to the side of the furnace. In smaller furnaces, this need be only a foot or so long and should taper with the large end at the furnace. Fig. 2 shows a sectional view of tilting-type crucible furnace equipped with a special combustion chamber.

10. To burn oil fuel efficiently in a furnace, it must first be finely divided in the liquid state and then vaporised. If sufficiently finely divided (or atomized) and evenly mixed with air, the vaporization progresses rapidly enough under the reduced vapor pressure to make combustion extremely rapid.

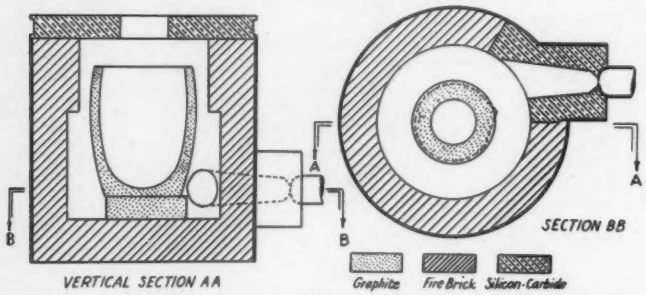


FIG. 2—SECTIONAL VIEW OF TILTING-TYPE CRUCIBLE FURNACE WITH SPECIAL COMBUSTION CHAMBER.

11. Within the past two or three years, a new crucible furnace has been put on the market which accomplishes almost simultaneous atomization, vaporization and combustion of the oil fuel. By using an oil pressure of over 2000 lbs. per sq. in. the oil in escaping from the orifice is exceedingly finely divided, mixes with the air and, by the time the mixture has traversed the relatively short combustion chamber, combustion has neared completion.

12. The oil is supplied by a high-speed, rotary- piston pump of consonant displacement. The furnace is started, by throwing a single switch. The atmosphere in the furnace is indicated by a calibrated draught gauge. Guided by this indicating gauge, the operator may adjust the furnace for oxidizing, reducing or neutral condition by simply regulating the air inlet. Fig. 3 shows a view of the apparatus.

13. Where natural gas is available at reasonable rates, it

constitutes the ideal fuel, although it is a little more expensive to use than oil. Like the latter, furnaces using natural gas should be provided with a combustion chamber sufficiently long to allow for full development of the flame temperature at the bottom of the crucible.

14. Comparisons between fuel oil and natural gas indicate that the production and transfer of the heat to the metal are more efficient with fuel oil than natural gas. For example, the most efficient installations using oil average about 35 gals. of fuel oil per ton of red brass (85-5-5-5) melted. A similar installation using

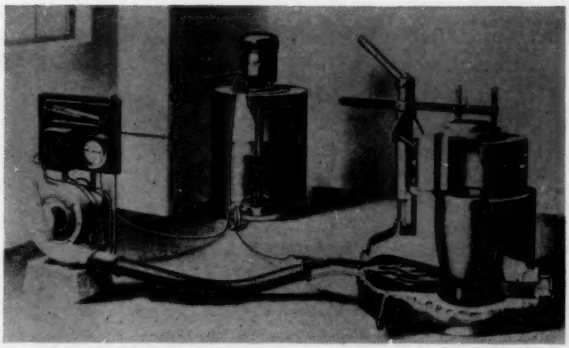

FIG. 3—SECTIONAL VIEW OF NEW TYPE FURNACE AND APPURTENANCES USING FUEL OIL AT 2000 LBS. PRESSURE. (*Courtesy United Furnace Engineering Co., N. Y.*)

natural gas will consume 8000 cu. ft. of gas per ton. The oil represents an input of 4,900,000 B.t.u., the gas 8,000,000 B.t.u. This observation received corroboration by some work done at the Great Falls plant of the Anaconda Copper Mining Co., where it was found that it requires 1441 B.t.u. to produce a pound of copper with oil fuel and 1670 B.t.u. with natural gas or about 16 per cent more.[1]

15. Another illustration of this comparison between oil and natural gas is had in melting pure copper in a 1200 lb. capacity tilting-type crucible furnace. The fuel consumption on a recent test was 50 gals. of fuel oil 28-30 degree Bé as compared with 13,000 cu. ft. of natural gas per ton of copper melted. The thermal inputs were 6,500,000 B.t.u. for the fuel oil and 13,000,000 for the

[1] Bardwell, E. S., *"A Comparison of the Use of Various Fuels in Copper Refining Furnaces,"* Tech. Pub. #457 A.I.M.E.

gas. As the theoretical heat required to heat and melt one ton of copper is approximately 500,000 B.t.u., the efficiency of the oil is 8 per cent and of the gas, 4 per cent.

16. This difference probably is due to the greater luminosity of the oil flame and the slower rate of flame propagation in the natural gas-air mixture.

17. If a burning natural gas-air mixture impinges on a refractory surface, the latter becomes incandescent and seems to act as a catalizer promoting the combustion. This is the so-called *surface combustion* principle.

18. In Table I, efficiencies of 50 per cent and 90 per cent are used for computing cost of thermal energy when electricity is used. The lower figure refers to furnaces using the arc principle for generating the heat. With this method, similar problems of conservation of the heat and efficiency are encountered as with fuel fired furnaces.

19. The 90 per cent efficiency refers to electric furnaces of

FIG. 4—INSTALLATION OF TILTING-TYPE CRUCIBLE FURNACE 900 LB. CAPACITY USED IN MELTING NICKEL SILVER WITH OIL PRESSURE OF 2000 LBS. (*Courtesy United Furnace Engineering Co., N. Y.*)

the induction type such as the high frequency, coreless induction crucible furnace in which large tonnages of non-ferrous metals are melted in rolling mill practice. As this furnace employs graphite crucibles for non-ferrous melting and magnesite crucibles for steel and steel alloys and is relatively a new invention, it may be properly mentioned here. In these furnaces, the conductors of the primary circuit remain cool and the heat is generated almost entirely in the metal charge. The principle losses in electrical energy are in the conversion from low to high frequency and the line resistance; but, as stated, these are relatively small.

20. Regarding the quality of metal produced in the high frequency induction furnace, the following conclusion is included among the results obtained from some recent experiments on the strength and aging characteristics of nickel bronzes:[2]

> "Most of the melts considered here were made in a 40 lb. Ajax high-frequency furnace. Crucible melts (cf 180 lb. each) of some of the alloys were made in an oil fired pit furnace, and these indicated as good or better properties than those of the Ajax melts".

## DISCUSSES FURNACE REFRACTORIES

21. In a paper by H. E. White[3] given before this Association, the status of special refractories for non-ferrous foundry work was presented. The author gave figures covering a period of years which clearly demonstrated the growing trend toward the use of special refractories for furnace linings and covers. The term *special refractories* refers to materials which have a higher fusion than the common, best grade, fire brick. To fall in this class, the material should have a fusion point of 3000 degrees Fahr. or over.

22. The new furnace referred to under the heading of fuels as using high oil pressure, also makes use of a heated charging hopper. By use of this device, a full charge of bulky metal may be added at once and, at the same time, effect an economy in using the waste gases for preheating the charge. The hopper also serves to seal off the crucible contents from the flames in the furnace, a condition which was only partly true of the ordinary crucible fur-

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[2] Wise, E. M. and Eash, J. T., *"Strength and Aging Characteristics of the Nickel Bronzes,"* METALS TECHNOLOGY, v. 1, n. 1, 1934.

[3] White, H. E., *"Care and Maintenance of Fuel Fired Furnace Linings in the Nonferrous Foundry,"* TRANSACTIONS A.F.A., v. 38, 1930.

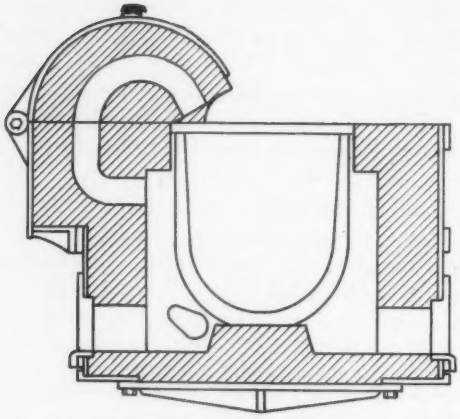

FIG. 5—SECTIONAL DRAWING OF ALUMINUM MELTING FURNACES USING GRAPHITE CRUCIBLES. (*Courtesy Fisher Furnace Co., Chicago, Ill.*)

FIG. 6—INSTALLATION OF PIT FURNACES, SIZES 225 AND 250, USING HARD COAL AND COKE.

nace. In the latter, the metal, unless covered, is exposed to the waste gases as they pass over the top of the crucible and out of the hole in the cover. Special refractories aided in the development of the charging hopper. Fig. 4 shows a tilting type furnace equipped with a preheated charging hopper.

23. Numerous examples have come to notice of crucible furnaces, both stationary and tilting types, where efficiency was low and crucible life materially reduced by burned out linings. Even in the case of coke-fired pit furnaces, a lining burned out so that the inside diameter is greatly enlarged, means waste of fuel, uneven heating, and causes shortened crucible life and slower melting. Roughnesses on the surface of the lining will deflect jets of flame against the crucible walls which will be correspondingly pitted and the crucible life reduced.

24. Even with a common fire-brick lining, these conditions can be avoided by periodically trowelling the inside of the furnace walls with any one of several high-temperature cements.

25. With special refractories, good conditions can be maintained with less attention and a better economy in the long run, in spite of a higher initial cost.

26. The majority of foundries now use a special refractory cover for crucible furnaces. These special refractories are of several types including sillimanite, high alumina and silicon carbide mixtures.

27. It has long been a recognized principle in crucible furnace lining construction to form the lower part with a larger diameter than the top. Even where this principle is not applied to the lining, somewhat the same effect is obtained by the contour of the crucible which, due to its barrel shape, allows more room at the bottom than higher up. However, this is hardly sufficient provision for efficient combustion. More room is required at the lower part of the furnace without increasing the lining diameter at the bilge of the crucible. This construction of the lining increases the velocity of the gases and tends to cut away the narrow or throat part of the lining. This development called for better refractories and there are a number of manufacturers in the country ably supplying this demand. The lining may now be designed on a theoretically sound basis and carried out in practice with minimum cost for upkeep.

FIG. 7—INSTALLATION OF FIVE, 375 LB. CAPACITY, TILTING-TYPE CRUCIBLE FURNACES USING NATURAL GAS FUEL. (*Courtesy Robertshaw Thermostat Co., Youngwood, Pa.*)

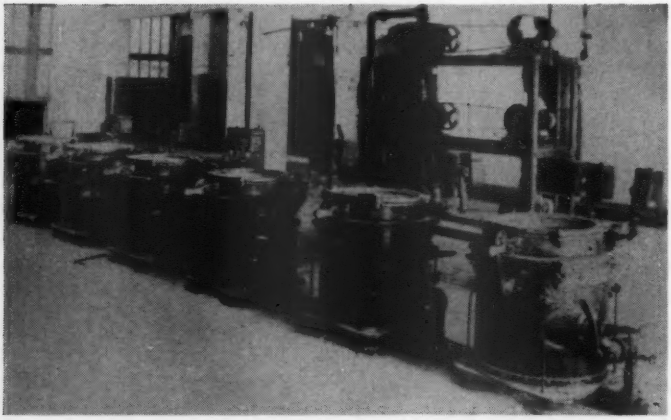

FIG. 8—INSTALLATION OF A BATTERY OF OIL-FIRED, LIFT-OUT TYPE CRUCIBLE FURNACES. (*Courtesy of Fisher Furnace Co., Chicago, Ill.*)

### CRUCIBLE LIFE EXTENDED.

28. The life of crucibles, on the average, has been more than doubled in the past ten years. This has been due to the introduction of the self-glazing crucible which affords protection to the graphite against oxidation. Just as notable has been the improved uniformity of service obtained from crucibles. These improvements have materially lowered the cost of the crucible method of melting.

29. There is a relatively small but increasing tonnage of special nickel, chrome, iron and copper alloys being melted in crucibles today which due to the higher fusion point of these metals imposes an added burden on the crucible. The manufacturers have either improved their product to meet these requirements or have developed special crucibles for these purposes.

### SPECIAL FURNACES FIND WIDE USAGE

30. A furnace, specially designed for melting aluminum in graphite crucibles, has been widely adopted and has been found efficient in operation and productive of sound metal. The distinctive features is a flue block which throws the flame down onto the bath of metal in the crucible. As the flame at this stage is neutral or slightly reducing, there is no danger of oxidation and the melting time is reduced at least one-third. Fig. 5 shows a sectional view of such a furnace.

31. A recent report from England advises that a graphite crucible furnace for melting aluminum has been designed and put in operation with a capacity of 1200 lbs. of aluminum.

32. Melting iron in crucibles has not been practised as extensively in this country as in England where piston rings, for example, are commonly cast from crucible melted metal. However, this practice has been on the increase here in the past year or two, either for melting special iron alloys or as supplementary equipment to the cupola. Inasmuch as relatively small amounts of iron of special alloy and purity can be melted in crucible furnaces at low cost, the method would seem to be designed for wider adoption.

### DESCRIBES TYPICAL CRUCIBLE FURNACE INSTALLATIONS

33. Fig. 6 shows a coke-fired crucible furnace installation. The semicircular arrangement of the pits, which gives each one an equal flue length to the stack is of special interest.

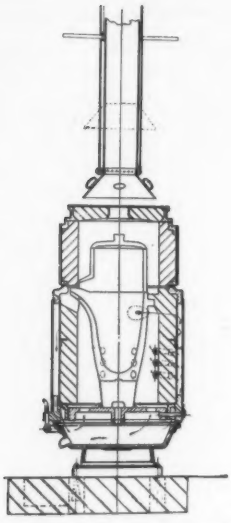

FIG. 9—TILTING-TYPE CRUCIBLE FURNACE MANUFACTURED IN ENGLAND. USES COKE FUEL AND IS EQUIPPED WITH PREHEATING CHAMBER. (*Courtesy Morgan Cruc. Co., England.*)

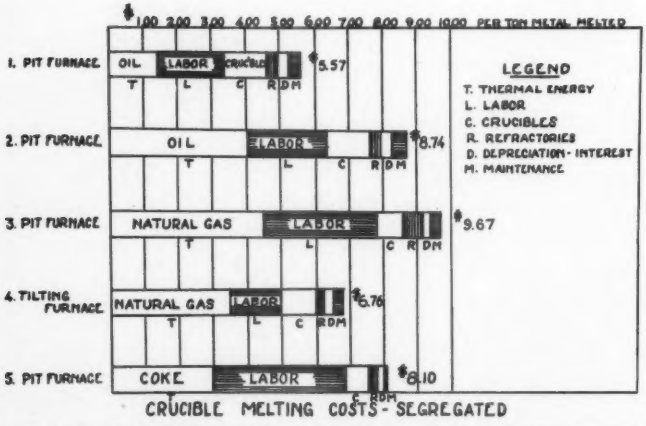


FIG. 10—GRAPHICAL PRESENTATION OF MELTING COSTS USING CRUCIBLE FURNACES AND VARIOUS FUELS. (BY PERMISSION OF *Metal Industry.*)

34. Fig. 7 shows a battery of five tilting-type crucible furnaces using natural gas fuel. The crucibles used are size No. 125 or 375 lb. capacity. This installation illustrates the efficiency and excellent working conditions to be obtained by a relatively small investment in crucible furnace melting equipment. The total investment was $2500 and the annual capacity, working daytime only, 300 days per year is 1400 tons of red brass.

35. Fig. 8 shows a battery of oil fired crucible furnaces. Fig. 9 illustrates a recent model of a tilting-type, coke-fired crucible furnace manufactured in England and widely used in Europe. This furnace features a charging hopper or preheater.

36. The forced draft is supplied through both bottom and sides. When melting copper, fuel consumption is said to be from 400 to 500 lbs. of coke per ton of metal melted and a 600 lb. heat can be melted in 1 hour and 50 minutes starting with a hot furnace. These figures check closely with American practice as given by Gillett.[4] An efficiency of 7 per cent is indicated.

37. Such furnaces as these offer an equivalent alternate to oil fired furnaces. Although they require more labor for tending the fires, the equipment for storing and pumping oil is eliminated.

## GIVES COSTS OF OPERATING MODERN CRUCIBLE FURNACE PLANTS

38. Fig. 10 shows segregated melting costs using crucible furnaces of various types. The figures include all items except metal loss. The latter varies in individual cases from less than 1 per cent to as high as 4 per cent, depending largely on the composition of the alloy, some of which make high metal loss unavoidable. The average of the five examples given is 1.78 per cent metal loss for red brass. Only two installations reported metal loss figures for melting yellow brass, one (No. 2) 4.16 per cent, the other (No. 4) 1.94 per cent or an average loss of 3.05 per cent.

[4] Gillett, H. W., *"Brass Foundry Practise in United States,"* p. 57.

## DISCUSSION

HUGH M. MILLER[1]: Does the speaker know of any development in the fixed type crucible pit furnace using oil or gas fuel where thought has been given to an additional combustion chamber of some size? I realize that you are limited in the size of the furnace area in which your crucible stands, but if it were possible to build a combustion chamber outside of the actual pit furnace, you would have a large space for combustion and could decrease the velocity of your fuels through that furnace and cut down your erosion as well. The average pit furnace lining, from the standpoint of refractories, takes an awful beating.

R. H. STONE: There is no reason why the combustion chamber could not be added to such a type of furnace, but I do not know of any such furnace that is thus equipped. Many of these furnaces are doubtless equipped with combustion chambers. But you should not be misled by the term "combustion chamber." It is really, as I show in some of the cuts, nothing more nor less than a little longer part, but it satisfied requirements. The condition that we sought to overcome by the introduction of the combustion chamber occurred where the nozzle was within 4 or 5 ins. of the crucible and the flame had no chance to develop at all. In some such installations, I have actually seen solid carbon on the off side of the crucible adhering to the crucible, whereas the top of the crucible will probably be hot enough to fuse; and, of course, the melting condition in a furnace like that would be just impossible. It would be slow and probably the metal would be overheated.

H. M. MILLER: Would it not be highly desirable to have a combustion chamber outside of your actual pit furnace chamber?

R. H. STONE: Yes, most certainly! The crucible furnace should be equipped with some type of combustion chamber, making allowance for that bad condition, which should not be allowed to continue.

MEMBER: Is it not possible, by bringing that burner in on the proper tangent to obtain the same results without this combustion chamber?

R. H. STONE: A tangential introduction of the flame is always desirable, but I do not believe you would get the best results unless you were to withdraw the burner at least 7 or 8 ins. from the inner edge of the port lining. It stands to reason that if you do not ignite a burning mixture until it actually enters the furnace, you cannot liberate the heat in that mixture quickly enough to keep the bottom of the crucible and the bottom of the furnace as hot as they should be. It should be ignited 7 or 8 ins. back before it enters the furnace proper.

It also depends on the type of burner and the type of fuel; for example, I mentioned in the paper that the efficiency of natural gas does not seem to be as high as the efficiency of fuel oil. By that I mean that when using natural gas, you have to introduce more B.t.u.'s to accomplish the same effect, than are necessary when using fuel oil. In that case, I think the effect is partly due to the fact that the heat is not liberated as rapidly from a burning naural gas and air mixture, as it is from a properly atomized oil and air mixture.

[1] Quigley Co. Inc., Philadelphia.

# High Chromium Cast Irons

By Garnet P. Phillips,* Moline, Ill.

**Abstract**

*Chromium is used in many alloys for heat and corrosion resistance and in this paper the author outlines the manufacture of high chromium irons containing approximately 20 to 35 per cent chromium. These irons are made in the electric furnace. They may be divided into two classes, one containing about one per cent carbon or less and the other more than one per cent. Melting, molding, and pouring procedure are outlined. The author states that he has used ferrochrome containing 0.7 to 0.8 per cent nitrogen with eminent success to produce finer-grained, low-carbon irons with good physical properties. Physical properties of typical irons are given in a table and Fig. 2 shows the microstructures of those irons in various states. The author also includes information on reasons for failures, thermal expansion, design, heat treatment, properties at elevated temperatures, and heat and corrosion resistant properties. A list of applications also is given.*

1. Cast Irons containing between approximately 20 and 35 per cent chromium have been produced by the company with which the author is associated for the past two years under licenses granted by the Electro Metallurgical Company. The metal has been used primarily in castings which are subjected to high temperature service conditions.

2. The various types of high chromium irons have good corrosion resisting properties in certain types of service.

3. All the high chromium cast irons produced by the author have been melted in an indirect-arc-type, electric furnace. The electric furnace was used to secure control of the carbon content and to obtain the high temperatures necessary for refining and casting the low carbon grades.

4. It is possible to produce high chromium irons in the

* Metallurgist, Frank Foundries Corp.

Note: This paper was presented at one of the sessions on Cast Iron Founding held at the 1934 Convention of the A. F. A.

cupola but the resulting metals have high carbon contents, large carbide grains and are relatively weak and brittle. However, such irons are suitable for certain types of service. As cast, they are either not machinable or very difficultly so. Their machining properties are improved by annealing at high temperatures.

5. Irons to be discussed in this paper have a carbon content of 0.75 to 2.00 per cent. The irons with a carbon content of about 1.00 per cent or slightly under, are readily machinable. As the carbon content increases, machinability decreases. Annealing renders the higher carbon irons more machinable.

## MELTING PRACTICE

6. Lump ferrochrome of the high carbon grade, containing approximately 5.00 per cent carbon, may be used to produce the higher carbon grades of irons. Low-carbon ferrochrome is used to produce the lower carbon grades. Within the past year, the author has employed nitrogen-bearing, low-carbon ferrochrome very successfully in producing finer-grained, low-carbon irons, with good physical properties. Low-carbon irons contain 1.00 per cent or less carbon, and normally have large coarse grains and low physical properties. The nitrogen content of the low-carbon ferrochrome used was between 0.7 and 0.8 per cent.

7. The furnace charge is melted down and superheated to 2950 to 3050 degrees Fahr., depending on the composition of the metal and type of castings to be poured. The chromium content of the charge must be from 8 to 10 per cent over the desired amount to allow for oxidation losses during melting and superheating. A considerable amcunt of slag is formed. This is removed from the metal before pouring.

## POURING AND MOLDING PRACTICE

8. When pouring large castings, such as furnace hearths, the metal is tapped into trolley ladles, transported to the molding floor and poured in the usual manner. When small castings are poured, the metal is caught at the furnace in the hand ladles and then poured without transferring the metal to another ladle. Pouring lips are removed from hand ladles as these normally will freeze over. Strainer cores are not used on the molds, and gates are made somewhat larger than those used for alloy gray irons as the metal is rather difficult to cast.

9. The castings shown in Figs. 1 and 2 give an idea of the sizes of castings poured with high chromium irons. The large hearth plate casting, Fig. 2, weighs 800 lbs. while the small conveyor chain links weigh slightly over 1 lb. Experience has shown that an allowance of about ¼ in. per foot must be made for shrinkage in making patterns for castings in this type of metal.

## COMPOSITIONS AND PROPERTIES

10. Typical chemical analyses and physical properties are given in Table 1. Transverse tests were made on 1.20-in. diameter bars tested on supports 18 ins. apart. Modulus of rupture and ultimate modulus of elasticity were calculated from the transverse test data. Hardness tests were made on sections taken from the broken transverse test bars. Rockwell hardness values are the average of four tests in each case. Tensile tests were made on 0.80-in. diameter bars machined from transverse test bars.

11. Irons such as 1, 2, and 3, Table 1, are drilled and cut readily but are rather difficult to grind. Irons such as 4 and 5 are more difficult to machine, the difficulty increasing with increasing carbon content.

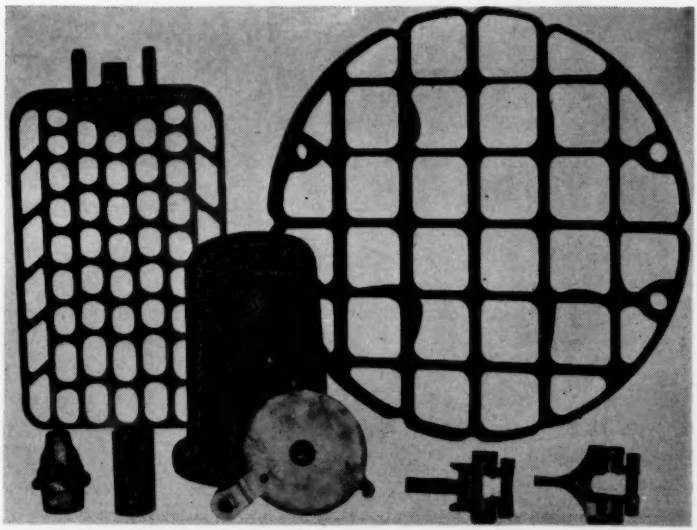

FIG. 1—TYPICAL CASTINGS MADE FROM HIGH CHROMIUM IRONS.

12. The value of the use of nitrogen bearing ferrochrome is apparent by comparing the physical properties of irons 1 and 2. It seems logical to expect improvement in the physical properties of all types of high chromium cast irons when nitrogen bearing ferrochrome is used.

13. The microstructures of the various types are shown in

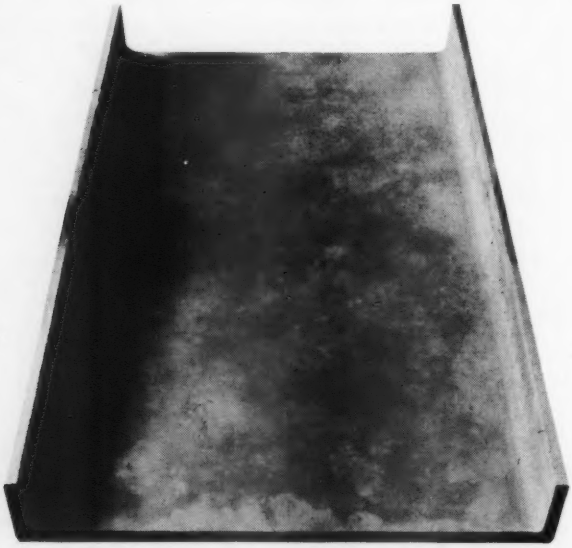

FIG. 2—THIS HIGH CHROMIUM IRON HEARTH PLATE CASTING WEIGHS 800 LBS.

Fig. 3. All microphotographs are at 250 diameters and all specimens were etched with ferric chloride, hydrochloric acid and water.

14. High chromium irons containing less than about 30 per cent chromium may be softened by annealing and may be hardened by quenching in oil or air from 1900 degrees Fahr. or higher. Irons containing over 30 per cent chromium are practically unaffected by heat treatment. Irons that are responsive to heat treatment may be hardened to a Brinell hardness in excess of 600. This type of iron may be used for abrasion resistant service.

**Table 1**

PHYSICAL PROPERTIES OF SOME HIGH CHROMIUM IRONS

| No. | Si. | C. | S. | P. | Mn. | Cr. | Ni. | Transverse test Load— lbs. | Deflection— Inch. | Modulus of Rupture— lbs. per sq. in. | Modulus of Elasticity— lbs. per sq. in. | Tensile Strength— lbs. per sq. in. | Hardness Rockwell | Brinell |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.[1] | 0.85 | 0.93 | 0.040 | 0.057 | 0.30 | 31.40 | ... | 3450 | 0.175 | 91,528 | 23,949,252 | 52,140 | C34.8 | 302 |
| | | | | | | | | 3000 | 0.150 | 79,590 | 23,949,252 | 47,440 | C34.4 | 293 |
| 2. | 1.43 | 0.78 | 0.030 | 0.090 | 0.95 | 33.70 | ... | 1880 | 0.100 | 49,876 | 22,500,000 | 32,500 | B104 | 262 |
| 3.[2] | 1.05 | 0.72 | 0.090 | 0.090 | 0.41 | 24.84 | ... | 4040 | 0.27 | 107,181 | 17,900,000 | 47,900 | B97.5 | 228 |
| | | | | | | | | 2865 | 0.19 | 76,000 | 17,900,000 | 41,720 | B95.5 Edge<br>B85.5 Midway—170 and<br>B41.0 Center— 153 | |
| 4.[3] | 1.18 | 1.57 | 0.109 | 0.107 | 0.31 | 24.70 | ... | 4670 | 0.23 | 124,000 | 24,200,000 | 73,800 | C39.5 | 363 |
| | | | | | | | | 3770 | 0.17 | 100,018 | 26,500,000 | 69,540 | C37.2 | 321 |
| 5.[4] | 1.96 | 1.84 | 0.057 | 0.032 | 0.65 | 23.95 | 0.42 | 4285 | 0.19 | 113,600 | 26,900,000 | 85,600 | B108.2 | 341 |

[1] No. 1 iron made with nitrogen bearing ferrochrome. The two sets of values of physical properties were obtained on finer grained and coarser grained specimens respectively.

[2] The two sets of values of physical properties given for iron No. 3 are for finer grained and coarser grained specimens respectively.

[3] The two sets of values of physical properties given for iron No. 4 are for "as cast" and annealed specimens, respectively. Annealed specimen of iron No. 4 annealed at 1850 degrees Fahr. for 3 hrs. and slowly cooled.

[4] No. 5 iron annealed at 1800 degrees Fahr. for 3 hrs. and slowly cooled.

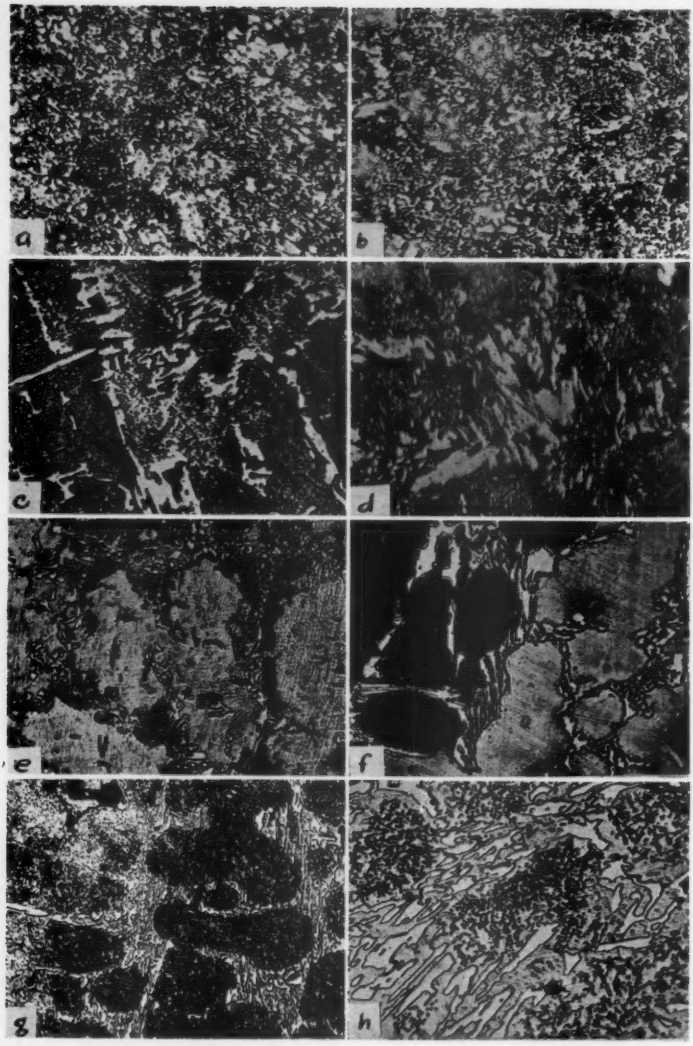


FIG. 3—MICROGRAPHS AT 250X OF IRONS GIVEN IN TABLE 1. SPECIMENS ETCHED IN FERRIC CHLORIDE, HYDROCHLORIC ACID AND WATER. A, IRON NO. 1, FINE-GRAINED STRUCTURE; B, IRON NO. 1, COARSE-GRAINED STRUCTURE; C, IRON NO. 2, AS-CAST; D, IRON NO. 3, FINE-GRAINED STRUCTURE; E, IRON NO. 3, COARSE-GRAINED STRUCTURE; F, IRON NO. 4, AS-CAST; G, IRON NO. 4, ANNEALED; H, IRON NO. 5, ANNEALED.

## HEAT RESISTING APPLICATIONS

15. Among the successful applications found for high chromium cast irons may be listed the following:

(1) Conveyor chain links used in heat treating furnaces.
(2) Lead pot grids.
(3) Oil burner parts.
(4) Furnace hearths.
(5) Boiler hearth parts.
(6) Exhaust manifolds.
(7) Die casting machine nozzles.
(8) Trays used in furnaces.
(9) Plates for receiving hot clinker for cement manufacture.
(10) Lead pots.
(11) Annealing boxes.
(12) Ornamental castings.

16. Failures have occurred in parts made with high chromium irons that have been subjected to stresses due to localized heating and to sudden thermal shock.

17. In general, the high chromium irons are finding heat-resisting service applications where gray and alloy gray irons will not withstand the service conditions and where the more highly alloyed nickel-chrome and other types are considered too expensive. In some instances, the high chromium irons are better suited than any other materials tested.

18. The high chromium irons have about the same coefficient of thermal expansion as ordinary gray iron. The tensile strength of the metal decreases with increasing temperature over about 1000 degrees Fahr. At about 1800 degrees Fahr., approximately 10 per cent of the as-cast tensile strength is retained.

19. Castings poured with high chromium irons should be as uniform as possible in metal section. Very heavy sections should not be used. Abrupt changes in metal sections and sharp corners should be avoided. Ordinarily, the metal sections cast will be between 5/16 and ¾ in. Uniformity of section is extremely important in preventing "heat cracking" due to differences in expansion in varying metal sections.

20. In general, all of the high carbon types should be annealed to relieve casting strains, before being put into service.

21. The material may be used regularly at temperatures up to 1800 degrees Fahr. and for short periods up to 1900 degrees Fahr.

## CORROSION RESISTANCE

22. High chromium irons have good resistance to atmospheric corrosion, and to nitric, sulphuric, and mixtures of nitric and sulphuric acids. They have been found reliable for dilute phosphoric and lactic acids, for numerous salt solutions, and for caustic soda solutions. In contact with molten lead and aluminum, they have given excellent service with practically no warpage.

23. In general, the lower carbon grades are the more corrosion resistant. The corrosion resistance has been found to decrease with increasing carbon content, although this may be partially offset by increase of the chromium content.

24. The outstanding characteristics of the high chromium irons are their excellent growth and oxidation resistance. In addition, the high carbon grades have very good abrasion resistance so that their field of application should broaden considerably.

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## DISCUSSION

MEMBER: How is the grain size in the first two irons controlled?

MR. PHILLIPS: The No. 1 iron had nitrogen bearing ferrochromium in the mixture resulting in finer grained metal. The No. 2 had the ordinary low carbon, ferrochromium in the mixture resulting in coarser grained metal.

J. S. VANICK[1]: It seems to me that these compositions are misnamed in calling them cast irons because the carbon contents are extremely low. None of them run over 1.90 per cent total carbon. Some of them drop to as low as 0.90 per cent carbon. That, by definition, in the carbon-iron system would place them in the class of steel.

As related to cast iron compositions, the physical properties that you find in Table 1 are comparable to very good grades of high-test iron, either heat-treated or "as cast," but comparisons with steel compositions are not exceptionally good.

The next feature in which this matter of definition becomes entangled is the fact that while this type of product can readily be made in an electric furnace in any foundry, it really requires bringing out a low carbon composition that is not producible in other types of melting equipment such as the gray iron foundryman is accustomed to use, namely, the cupola.

I believe that before we present these types of compositions as falling

[1] International Nickel Co., New York City.

within the definition of cast iron, and before we accept them as cast iron even though they contain an appreciable amount of silicon, we have some work for the Committee on Definitions and Nomenclature to decide upon where they belong.

MR. PHILLIPS: I would say that Mr. Vanick's criticism of calling them cast iron is one for which there is no definite answer at present. We all know that great difficulty is found in defining what is cast iron and what is steel. I think it is becoming more difficult right along.

The physical properties, such as lack of ductility, probably would help classify them. That would be a reason for calling them cast irons rather than steels. It is more or less a matter of opinion in definition. Certainly the low-carbon grades might be called high-chromium steel. The materials are not gray irons as they have no graphite. This department of our business might be considered an infant industry. While we have been producing these high chromium irons for the past year and a half, it is a fact that the production has been limited to only occasional heats being poured and the total volume of business does not represent over a quarter of one per cent of our business based on the dollar sales value of the production.

MEMBER: It has been said that the first irons were machinable. Were they machinable under ordinary practice, or did they require the use of tools of special steels?

MR. PHILLIPS: They do not require any special tool steels. We find that we can drill the material at high speed with an ordinary high-speed drill and the material can be cut with the same cutting tools that are used on chrome-nickel gray irons, although the cutting speeds are considerably lower.

MEMBER: I would like to ask about the thermal shock resistance of this material and what application is being made. I have had some experience with this material and I found that its lack of thermal shock resistance is its chief drawback.

MR. PHILLIPS: One case that I recall immediately is one in which we were making some experimental castings for heat-treating furnaces—some pot castings. We were not at first successful there. The flame would apply to one spot only and the castings would crack immediately although the design was not the best for the service requirements.

I might add that in general in the heat resisting applications, the material either is very good or it is no good at all. It will generally fail immediately or it will last a very long period of time, although failures are frequently due to design about as much as to metal characteristics.

MEMBER: How high a chromium content is it practicable to use in a cupola operation?

MR. PHILLIPS: We have not produced the material in the cupola. As far as I know, there is no particular limit.

E. K. SMITH[2]: I would probably answer that question roughly by saying that we have found that almost any amount of chromium can be

[2] Electro Metallurgical Co., Chicago.

melted. I have seen it melted in the cupola up to 40 per cent, using chromium briquets. It is practical to make a cupola metal up around 15 per cent chromium and, personally, I do not like to see very much over 15 per cent when melting with the cupola.

# The Selection of a Suitable Method of Polishing Cast Iron for Microscopic Examination

By M. F. Surls*, East Lansing, Mich.

**Abstract**

*In the past several years, many methods have been introduced for the polishing of cast iron specimens. In this paper, the author explains the development of a polishing procedure for cast iron and outlines the principles underlying the present methods of procedure. A table shows 11 methods now used in various laboratories for polishing cast iron specimens. In preparation of this work, the author submitted two samples of gray cast iron to several well-known laboratories and shows by photomicrographs the results of the various methods used. He recommends a polishing procedure based on his findings and explains some of the difficulties encountered in polishing cast iron specimens. He also explains that certain types of cast iron are more difficult to polish than others. Results of his investigation show that similar results were obtained by four different polishing methods and that regardless of the method used, the final success depends largely on the skill and experience of the operator. The author also found that a satisfactory method for general work involves the use of emery papers for the intermediate steps and a finish with rouge. By the use of those methods, a specimen can be polished in 5 to 10 minutes.*

1. The polishing of cast iron for the purpose of microscopic examination has been the object of much investigation during the past few years. As a result, various methods have been described in published articles, and in addition many variations of these methods, which have never been published, are in use. The selection of a suitable polishing procedure is a difficult task because so many methods have been recommended.

2. Because of the many methods recommended, considerable confusion of thought has arisen concerning this subject. The au-

* Metallurgist, Michigan State College.

Note: This paper was presented at a session on Cast Iron at the 1934 Convention of A.F.A.

thor hopes to clarify this situation by: (1) comparing results obtained by different polishing methods, (2) showing that the skill of the operator is more important than the method employed, and (3) describing some of the difficulties in technique encountered and methods of overcoming them.

## THE DEVELOPMENT OF POLISHING METHODS.

3. Size, shape and distribution of the graphite particles along with the structure of the matrix have a profound influence on the physical properties of the casting. These characteristics make microscopic inspection of extreme importance in both routine examination and in development work. Therefore, the proper preparation of the polished surface to show its true character is of the greatest value.

4. The first microstructures of cast iron were prepared by the same methods which had been giving reliable and comparable results with steel. Later it was realized that these methods removed the fragile graphite and enlarged the cavities which remained. On viewing the sample through the microscope, these cavities appeared much larger than the actual size of the original graphite particles. A search for a method that would overcome this difficulty has resulted in the development of numerous methods, many of which seem to give satisfactory results.

## PRINCIPLES OF PRESENT METHODS

5. All of these later methods of polishing cast iron depend upon the polishing being done in such a way that the graphite is retained in its cavity. This prevents the edges of the cavities from becoming beveled and consequently the actual size of the particles may be observed.

The steps in all of these polishing methods may be divided into three divisions, viz., rough grinding, intermediate polishing, and final polishing.

6. *Rough Grinding.* The purpose of the rough grinding operations is to obtain a plane surface. This may be accomplished by grinding on rough emery paper or on an emery wheel.

7. *Intermediate Polishing.* The intermediate and final polishing operations vary considerably with different methods and are listed in Table I. The purpose of the intermediate polishing operation is to reduce the depth of the scratches on the surface to the point where they are shallow enough to be removed by the final

**Table 1**

VARIOUS POLISHING METHODS FOR CAST IRON

| METHOD No. | INTERMEDIATE POLISHING STEPS | FINAL POLISHING OPERATION |
|---|---|---|
| 1 | # 1 - 0 - 00 - 000 - 0000 metallographic papers on vertical disks run at 1750 r.p.m. | Platers rouge on horizontal disk covered with velvet that has the nap worn off. Moistened with water. |
| 2 | #1G-1F-0-00-000-0000 metallographic papers. By hand. | Wet parchment stretched over plate glass and charged with water graded alumina. By hand. Finish on rouge on velvet pad. |
| 3 | Polishing papers of increasing fineness down to and including No. 0000. | Jewelers rouge in cake form on horizontal disk covered with billiard cloth. Moistened with water. |
| 4 | Polishing papers of increasing fineness down to and including No. 0000. Used No. 0000 paper glazed with graphite. | Jewelers rouge in cake form on horizontal disk covered with billiard cloth. Moistened with water. |
| 5 | Polishing papers of increasing fineness down to and including No. 000. Used No. 000 paper glazed with graphite or soapstone. | Alumina or magnesia on horizontal disk, covered with heavy silk satin dull side up. Moistened with water. |
| 6 | Polishing papers of increasing fineness down to and including No. 00. | Horizontal polishing disk covered with pitch and levigated alumina. Moistened with water. |
| 7 | Polishing papers of increasing fineness down to and including No. 00. Followed with No. 320 and No. 600 Alundum. Moistened with water. | Levigated Alumina on napless cotton cloth. |
| 8 | By hand on No. 00 and 0000 polishing paper, or No. 0-000-0000, the No. 0000 used on a horizontal disk. Then chrome buffing compound on horizontal disk covered with billiard cloth. Polish dry. | Chrome grain polishing compound on horizontal disk covered with velchamee. Slightly moistened with water. |
| 9 | No. 0, 20, 30 polishing paper. Stainless steel and chrome buffing compounds on horizontal disks covered with canvas and broadcloth respectively. Both moistened with water. | Nickel buffing compound on horizontal disk covered with broadcloth moistened with water. |

(Continued on next page)

**Table 1—Continued**

VARIOUS POLISHING METHODS FOR CAST IRON

| METHOD No. | INTERMEDIATE POLISHING STEPS | FINAL POLISHING OPERATION |
|---|---|---|
| 10 | Stainless steel buffing compound on vertical leather wheel. Chrome buffing compound on leather wheel or horizontal disk covered with billiard cloth. | Jewelers rouge in cake form on horizontal disk covered with billiard cloth. Moistened with water. |
| 11 | Polishing paper No. 240, 320 and 400 on horizontal disk. | Powdered rouge on horizontal disk covered with velvet. Moistened with water. |

wheel. This must be done so that the particles of graphite are not removed from the surface. It should be noted that, in the majority of cases, emery polishing papers of increasing fineness are used for these intermediate steps. Such materials as stainless steel buffing compound, chrome buffing compounds, and disks covered with paraffin or pitch impregnated with abrasives have been used in a few instances.

8. *Final Polishing.* The final polishing is done by various methods. Probably the most popular is the use of fine rouge on a disk covered with either velvet or billiard cloth. The success here depends largely on the grade of rouge used. Some use powdered rouge worked into a damp wheel while others use the cake form. Some rouges give satisfactory results while others do not. The only method by which a suitable rouge can be selected is by trial of various samples.

9. Other abrasives used for final polishing are levigated alumina, magnesium oxide, and several commercial polishing compounds. A wide variety of cloths are used for holding the various abrasives. However all of the cloths are of the type which have no nap or at most a very short nap.

## COMPARISON OF METHODS

10. To compare the results obtained by various polishing methods, two specimens of gray cast iron, designated as irons Nos. 1 and 2 containing approximately 3.40 per cent and 3.10 per cent total carbon respectively, were selected and samples of each sent to four well-known laboratories. The samples were polished and photomicrographs at 100 and 500 magnifications were submitted. Results are shown in Figs. 1, 2 and 3 for No. 1 iron and Figs. 4, 5 and 6 for No. 2 iron.

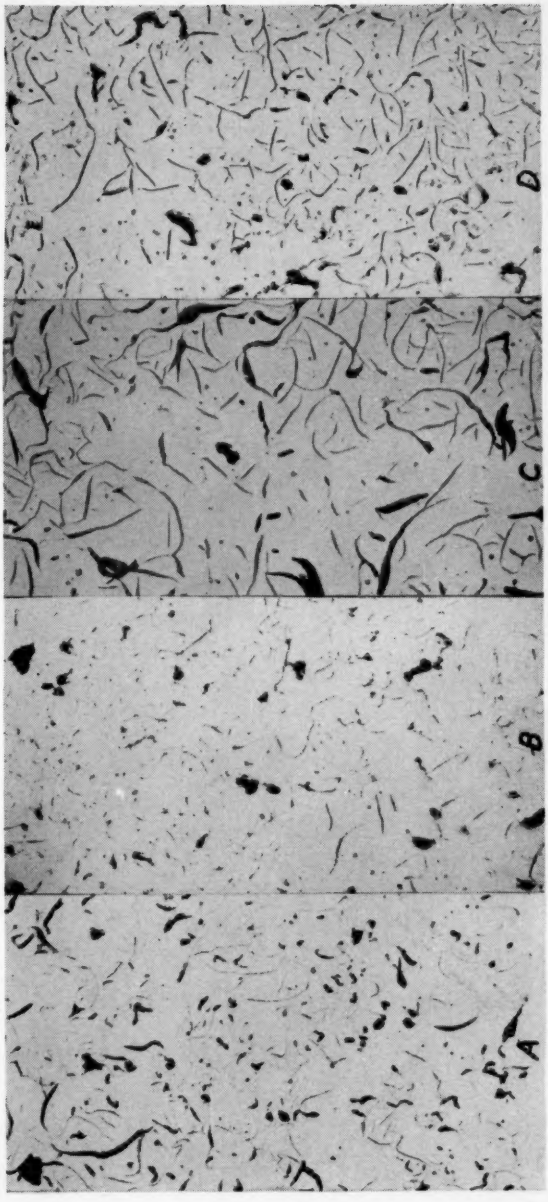


FIG. 1—IRON NO. 1 POLISHED BY FOUR POLISHING METHODS. *A* POLISHED BY METHOD NO. 8, TABLE I, *B* BY METHOD NO. 9, *C* BY METHOD NO. 5 AND *D* BY METHOD NO. 11. UNETCHED AND MAGNIFIED 100X.

FIG. 2.—SAME AS FIG. 1, UNETCHED, MAGNIFIED 500X.

FIG. 3—SAME AS FIG. 1, ETCHED, MAGNIFIED 500X.

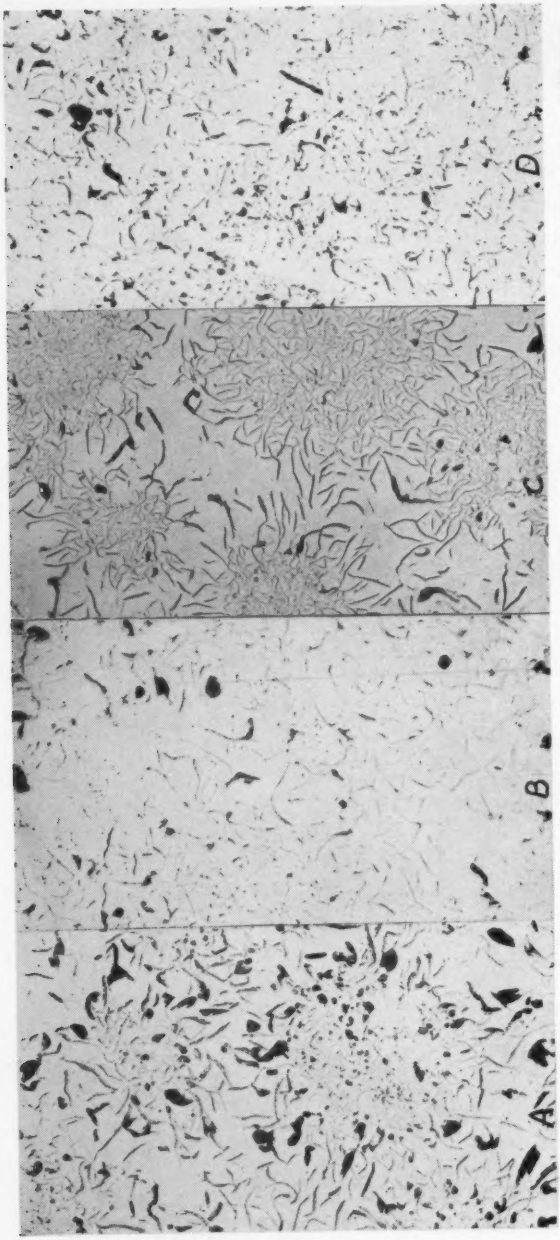


FIG. 4—IRON NO. 2, POLISHED BY FOUR METHODS, UNETCHED, MAGNIFIED 100X. *A* POLISHED BY METHOD NO. 8, TABLE I, *B* BY METHOD NO. 9, *C* BY METHOD NO. 5 AND *D* BY METHOD NO. 11.

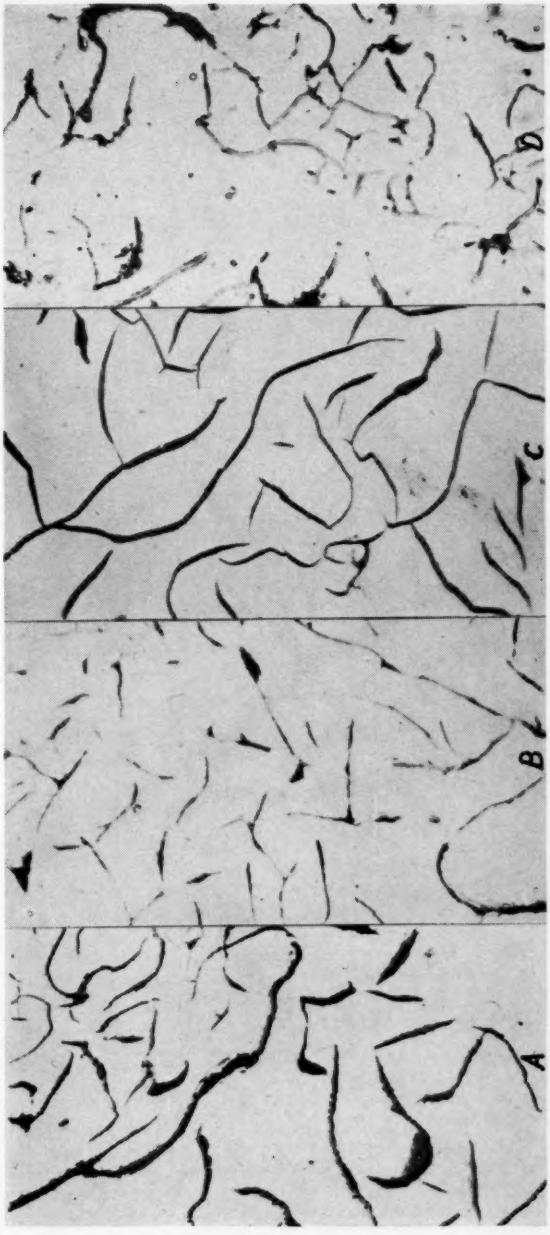


Fig. 5—Same as Fig. 4, Unetched, Magnified 500x.

FIG 6—SAME AS FIG. 4, ETCHED, MAGNIFIED 500X.

11. The photographs for iron No. 1 show a fairly uniform graphite distribution so that differences in appearance, especially at 100 diameters, can be attributed to differences in polishing results. In Figs. 1, 2 and 3, micrographs A and D agree very closely. In Fig. 1, B appears to have less graphite visible than samples polished by other methods. Fig. 2-B shows the graphite flakes to be poorly defined. This does not show in the etched sample of B, Fig. 3. C in all three figures shows the opposite tendency in that the flakes appear much broader than in either A, B or D.

12. Photomicrographs of iron No. 2, shown in Figs. 4, 5 and 6, show considerable irregularity in graphite distribution but a visual inspection revealed that each photograph is similar to some area on the specimen. Photograph B, Fig. 5, again shows the same tendency toward poorly defined graphite flakes that is shown in B, Fig. 2. This tendency is not so noticeable in the etched sample.

13. From these figures it can be seen, first that there is some difference in the results obtained by the four methods shown; second, that this difference is not very great, and third, that the etched samples agree more closely than do the unetched ones.

## RECOMMENDED POLISHING PROCEDURE

14. The following method is recommended for polishing irons containing free graphite and other inclusions. The technique is easy to acquire but good results cannot be obtained until the laboratory worker has gained some skill in its manipulation. This method is rapid and results can be obtained which are superior to those procured by many other methods.

15. *Rough Grinding.* Grind on the flat side of an emery wheel of about 60 mesh grit. The purpose of this operation is to remove the saw marks and to obtain a flat surface. A plane surface at this point will save time in the following step. The sample should be kept cool during grinding by dipping it frequently in water.

16. *Intermediate Polishing.* Grind successively on emery papers of 240, 320, and 400 mesh grit[1]. These papers are mounted on horizontal disks revolving at 600 r.p.m. The specimen should be ground long enough on each paper to remove all of the scratches from the previous paper, and should always be held so that the direction of polishing is at right angles to scratches from the previous paper. Before changing from one paper to another of finer

[1] The grit should be of uniform size on each paper to prevent the formation of deep scratches.

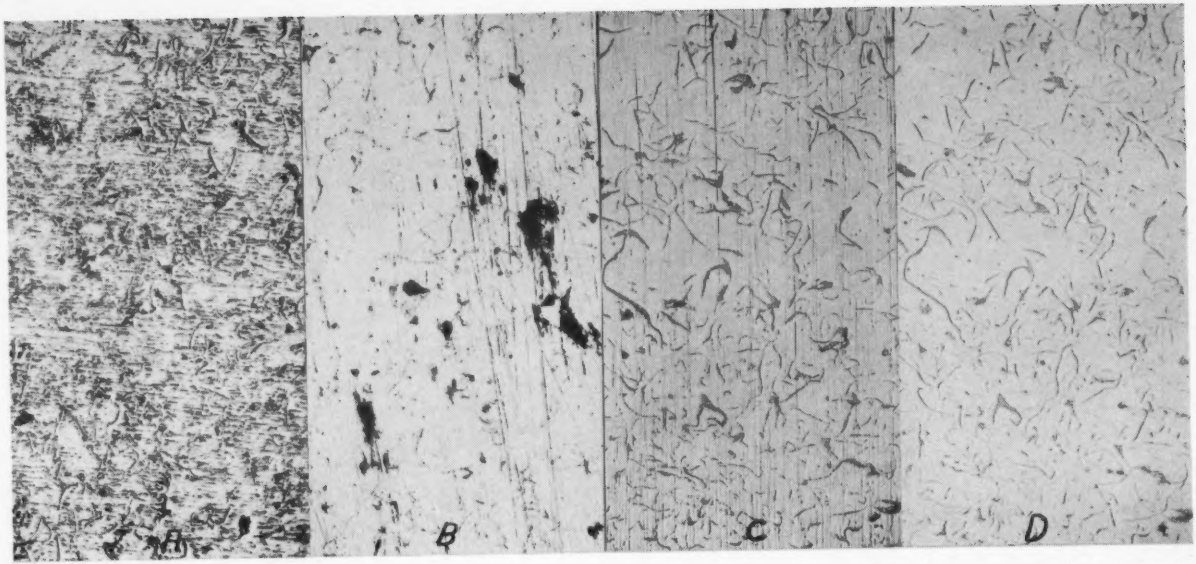


FIG. 7—*A*, SAMPLE POLISHED ON EMERY PAPER WITH 400 MESH GRIT WHICH WAS DULLED. SURFACE BADLY STAINED. MAGNIFICATION, 100X. *B*, SAMPLE POLISHED ON EMERY PAPER WITH 400 MESH GRIT MOISTENED WITH WATER. GRAPHITE INCLUSIONS BADLY TORN OUT, MAGNIFICATION, 100X. *C*, SAMPLE PROPERLY POLISHED ON 400 MESH GRIT, MAGNIFICATION 100X. *D*, SAMPLE PROPERLY POLISHED WITH ROUGE, MAGNIFICATION, 100X.

grit the specimen should be washed to remove any abrasive that might adhere to it.

17. The speed at which the disk revolves is an important factor. Too high a speed causes the grit to become dull rapidly. The finer the grit the more pronounced is this tendency. The papers must be removed as soon as the grit becomes dulled, as a dull abrasive cuts very slowly and a brown stain appears on the surface of the sample. This stain can be seen by the naked eye if the surface is held properly in the light. Microphotograph A, Fig. 7, shows a sample polished on a paper with a dulled 400 mesh abrasive. The surface of the piece was badly stained. The 400 grit paper usually can be used for about 6 or 8 specimens while the coarser grits can be used for a greater number.

18. All emery papers must be used without a lubricant. If water is used on the paper the scratches will be deep and the graphite inclusions will be torn out as shown in B, Fig. 7. This sample was prepared on a 400 grit emery paper lubricated with water.

19. The specimen should be finished on the last paper with a very light pressure as this produces shallow scratches which are removed readily on the final wheel. A specimen properly polished on the final emery paper is shown in C, Fig. 7.

20. *Final Polishing.* This operation is done on a horizontal disk covered with velvet. Most of the nap is removed from the velvet by holding the back of an old hacksaw blade against the revolving disk. The cloth then is moistened with water and impregnated with a good grade of fine rouge.[2] About a teaspoonful of the rouge should be worked into the moist cloth. The specimen should be washed thoroughly, to remove all abrasive picked up from the last emery paper before starting the final polish. The cloth is kept slightly moist and the specimen is rotated during the polishing operation. Polishing should cease as soon as all scratches from the previous disk have been eliminated. The specimen should be washed with water to remove all rouge and then dried to prevent staining.

21. The amount of water used and the speed of the disk are two factors which must be controlled carefully. Some water must be used to prevent heating of the sample and the staining of the surface. However, the greater the amount of water the more diffi-

[2] Many rouges will not give satisfactory results and there are no definite specifications that can be used when buying. A rouge #228 supplied by the Bausch and Lomb Optical Co. has given good results thus far.

cult it becomes to retain the inclusions. The higher the speed of the disk, the greater the quantity of water that is necessary to prevent this staining. Therefore, in polishing samples in which it is extremely difficult to retain the graphite, the speed of the disk should be about 400 r.p.m. and with not more than 8 or 10 drops of water added per minute.

22. For samples which are easier to polish and retain graphite inclusions, the speed of the disk and the amount of water can be increased slightly. A speed of 600 r.p.m. and 15 to 20 drops of water per minute can be used for most irons. It is recommended that the speed and amount of water be kept within this range and that the cloth be kept well charged with rouge at all times.

23. The specimen should be examined under the miscroscope after it has been washed and dried to make sure the polishing has been done properly. A photomicrograph of a properly polished specimen is shown in D, Fig. 7. The graphite inclusions are still retained and the outline of each is sharp and well defined. In some irons, there may be shallow graphite flakes which are almost impossible to retain. In case such an iron is encountered, some cavities will be formed even with the best polishing technique.

## POLISHING DIFFICULTIES ENCOUNTERED

24. A description of some of the difficulties encountered in the polishing of irons containing free graphite and methods to overcome them constitutes the following sections of this paper.

25. *Intermediate Polishing.* Intermediate polishing must leave the graphite intact and only very shallow scratches on the surface. This can be done readily with a series of emery papers of increasing fineness used without a lubricant. The papers must be discarded when the grit becomes dulled. Some attempts were made to use disks covered with paraffin impregnated with abrasive, but the grit soon became dulled and the disk had to be reconditioned before further use.

26. *Removal of Graphite.* After the sample is properly prepared for the final wheel there are still many difficulties to be encountered. Methods used for polishing steel applied to gray cast iron removed much graphite leaving enlarged cavities. The factors which seem to influence the removal of graphite inclusions are: (1), the kind and amount of lubricant used; (2), brushing action of the long nap found on some cloths, and (3), the rolling action of the grit.

27. *Lubricant.* In the final polishing operation, water is the most common lubricant. If too much is used, the tendency to remove the graphite is much greater than when the disk is only slightly moistened. From 10 to 20 drops per minute usually will give good results. It may be necessary to deviate from this range with some irons, but, as an operator becomes more familiar with his method, he acquires skill in judging the amount of moisture to use.

28. *Type of Polishing Cloth.* A cloth with a long nap seems to cause more graphite removal than one with a very short nap. This probably is due to the fact that the nap acts in the same way as a large number of very small brushes which have a tendency to break out the fragile graphite particles. For the polishing method recommended by the author, velvet with the nap worn off and billiard cloth both were found to give good results.

29. The rolling of the grit under the sample during polishing also may be a cause of graphite removal. This rolling action is caused in part by having a large quantity of water on the wheel.

30. *Types of Abrasives.* The removal of graphite is a greater problem with some abrasives than with others. However, as can be seen from Table I, many different abrasives have been used with good results. The success depends to a large extent on using the proper technique for each abrasive.

31. Not all grades of rouge give satisfactory results. As there are no definite specifications that can be given, it is necessary to pick a rouge by trial of various samples. Duplicate samples of the same grade ordered from the same manufacturers may not give the same results.

32. *Comet Tail Effect.* Another defect that often is encountered is that the particles tend to pull out in the direction of polishing. This causes a small comet tail to appear as shown in photograph A, Fig. 8. This usually can be prevented by rotating the sample while polishing on the final wheel.

33. *Cold Working of Polished Surface.* In some cases, the graphite may be obscured by a thin layer of worked metal which is smeared over the surface. This is caused by use of papers with dulled grit. Dulled grit causes cold working instead of a free cutting action and the metal smears over the graphite inclusions. The same is true where the grit is held in paraffin. If a heavy layer of worked metal is produced during the intermediate polish-

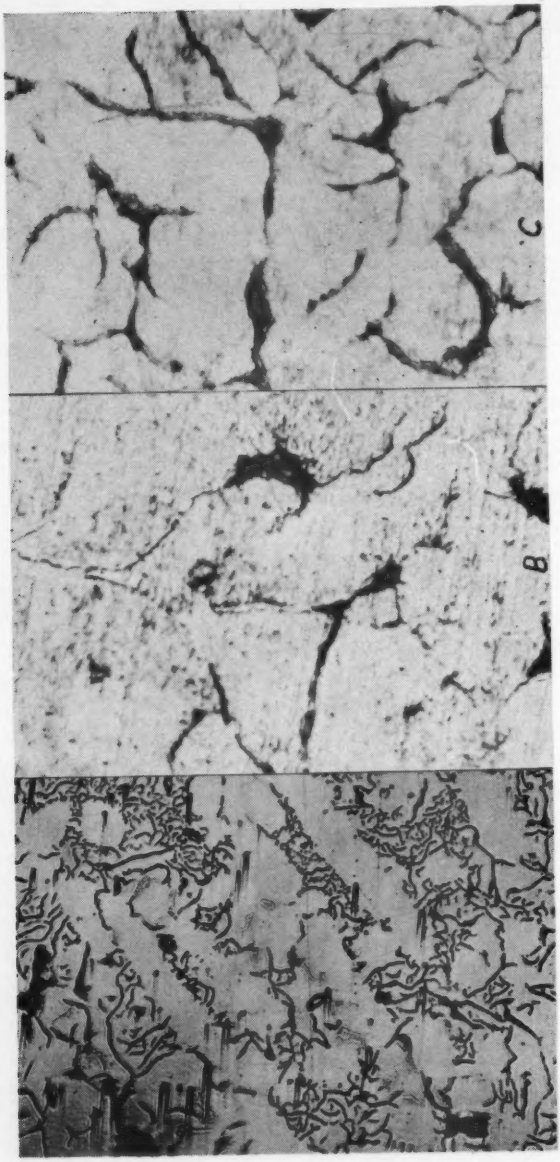


FIG. 8—SOME DEFECTS FOUND IN POLISHED SPECIMENS. *A*, SHOWING A "COMET-TAIL" EFFECT, MAGNIFIED 100X. *B*, GRAPHITE COVERED WITH A LAYER OF WORKED METAL, ETCHED AND MAGNIFIED 2800X. *C*, SAME SAMPLE AS *B* AFTER PROPER POLISHING MAGNIFIED 2800X.

ing steps, it will require excessive polishing on the final disk in order to remove it.

34. Some cold working often will occur during the final polishing operation. A small amount of surface flowing due to this cause is not particularly detrimental, as it can be removed by etching. (See B, Figs. 2 and 3.) It can be detected readily by examining the samples under the microscope before and after etching. The formation of a heavy worked surface should be avoided, as etching will not remove it and consequently neither the graphite particles nor the matrix will be revealed in their correct form. A badly worked sample is shown in Fig. 8B. Fig. 8C shows the same sample after proper polishing.

35. With the proper grade of rouge being used on the final disk, the amount of cold working produced is reduced to a minimum. However, some may be produced, if the rouge is used too dry.

## Polishing Stands

36. Some thought should be given to the type of polishing stand used. When a friction drive is employed, it is almost impossible to eliminate vertical movement of the disk. A disk running without vibration makes satisfactory polishing much easier. In the laboratory used by the author, horizontal disks are used with the vertical shaft mounted in a radial thrust ball bearing to eliminate all vertical end play. The shaft is driven by a V-belt. The disks are mounted so that they can be easily and quickly removed and replaced and will always run true when in place.

## Variations in Metal

37. When polishing cast iron, it must be kept in mind that there are many variations in the metal itself. Some irons polish easily while others polish only with difficulty. An iron consisting of pearlite, or a harder material in the matrix, and graphite in the form of small flakes is much easier to polish than an iron which contains considerable ferrite and large irregular graphite areas. In Fig. 9, irons A and B are prepared easily while C is an iron rather difficult to polish without removing some of the graphite.

38. This difference in irons may account in part for the fact that two operators using the same method may not have the same degree of success. It is not to be expected that any polishing method will overcome the variations in the iron, unless the operator

FIG. 9—*A* AND *B* SHOW IRONS WHICH POLISH EASILY, MAGNIFIED 500X. *C* IS AN IRON DIFFICULT TO POLISH, MAGNIFIED 800X.

has sufficient skill and experience so that he may change his technique to meet the different conditions.

## CONCLUSIONS

1. Similar results were obtained by four different polishing methods as shown by the photomicrographs.

2. Regardless of the method used, the final success will depend largely upon the skill and experience of the operator.

3. Some irons polish more easily than others. Therefore, the operator must always be alert to see that each sample is prepared properly.

4. The author has found that a satisfactory method for general work is to use emery papers for the intermediate steps and finish with rouge. A sample can be polished in from 5 to 10 minutes.

5. A polishing stand is recommended which is of such design that the disks will run true and without vertical or lateral vibration.

## ACKNOWLEDGMENT

The author wishes to express his appreciation for the many helpful suggestions offered by Prof. H. E. Publow while this work was being carried on.

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## DISCUSSION

R. SCHNEIDEWIND[1] (*Submitted in Written Form*): I find the photomicrographs of Figs. 1 to 6 especially interesting. To me, they indicate a rather unfortunate state of affairs in commercial laboratories. If you take Figs. 4, 5 and 6 as typical, I would say that the laboratory submitting the pictures labeled *C* is very good, whereas laboratories *B* and *D* are inferior. If we are to understand that these photographs are taken from different pieces of the same bar, the structures shown in Fig. 4 are misleading. Photomicrograph 4*C* clearly shows the structure of an iron which has been superheated and rather slowly cooled, giving a rosette structure. Fig. 4*A* also shows this structure but in a much less satisfactory manner. One could, however, interpret Fig. 4*A* the same as 4*C*. Figs. 4*B* and *D* are rather poor and do now show the structure. In Fig. 6, a similar state of affairs is shown. Fig. 6*C*, although slightly out of focus, shows what might easily be a representative section of the iron. The metallographer taking Fig. 6*A* selected a spot in the middle of the rosette, which is not truly representative of the iron. Fig. 4*B* is over-etched so that no idea could be given of the structure. Fig. 4*D* is etched unsatisfactorily, so that no grain boundaries are clearly defined.

It would be my opinion that Mr. Surls might go farther than showing how to polish, in pointing out that good polish must be coupled with good judgment in the making of photomicrographs so that the picture will be capable of intelligent interpretation.

L. A. DANSE[2], (*Submitted in Written Form*): The remarks on the selection of a suitable method for polishing cast iron have long been needed and we are glad to see them now published so completely. The development of one of the methods given in the paper occupied the entire time of one metallographer for a period of about 4 months, in this laboratory. Tryouts were made of numerous pieces of equipment and of many variations of the method. The desired method was one which would not remove the inclusions from steel nor the graphite particles in cast iron. It was found much more difficult to do a good job of polishing on cast iron than it was on steel. Accordingly, effort was concentrated on the cast iron.

It gives us a great deal of pleasure to see work like this report, in view of the fact that we have for years required that a metallographer know something about polishing. Anybody can do microscopic examination, but it takes a metallographer of a high degree of skill and a considerable degree of knowledge to properly prepare samples. The examination is quite simple, in view of the vast amount of literature available. However, where has there been anything of polishing, previous to this?

MEMBER: Speaking of water dripping on the polishing wheel to keep the sample cool, and the disadvantage of excessive water, would there

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[1] Research Engineer, College of Engineering, Dept. of Engineering Research, University of Michigan, Ann Arbor, Mich.

[2] Metallurgist, Cadillac Motor Car Co., Detroit.

be any objection to dripping on the minimum amount of water and then periodically immersing the sample in the pan of water without any swirling motion, to cool it during the polishing operation?

MR. SURLS: Our experience is that you get better results having the water dripping on the wheel rather than trying to immerse the sample in the water. If you immerse the sample in the water, you cool it all right, but your wheel is still dry and the minute you put the sample back you start to get a heating action again. If you put the water on the disk it seems to work much better.

MEMBER: Since the last operation with rouge must be made with water, what is the particular disadvantage in using the emery flour on the canvas for the intermediate operations?

MR. SURLS: In the cases where you use those abrasives, you must use some water as a lubricant, otherwise you will tear out a lot of graphite before you come to the final operation. That is the experience that we have had. The use of the emery papers up to the last step, gives us a means by which we can work the specimen down without disturbing those graphite flakes. We are simply cutting across the surface. Anything else we have tried, has always ripped the graphite flakes out rather than cut across them.

T. J. WOOD[3]: I would like to say that the Bayonne Research Laboratory of the International Nickel Company has been able to confirm Mr. Surls' experiences throughout in every last detail. We use vertically mounted emery papers up to No. 400 and then the graphite-coated worn surface on the last paper. From there we go directly to silk, final polishing cloth, using levigated alumina for the abrasive.

In addition to some of the precautions which Mr. Surls has mentioned, I would like to suggest that the size of the specimen has much to do with the success obtained in retaining graphite. It has been our experience that a small-sized specimen, perhaps between ⅜ or ¼ in. square, would give better results than larger specimens. The larger specimens will require more time on the wheel. If more time is required, it may lead to a general deterioration of the graphite structure.

Mr. Surls' remarks with regard to the softness of the specimen can also be confirmed. We find that with a hard specimen, it is much easier to retain the graphite. This method which we use is not entirely our own, but is based largely on the methods developed by Vilella.

A. I. KRYNITSKY[4]: I want to confirm the results obtained by the author and also to emphasize the undesirability of using water. In our work, we have followed the practice of Vilella with this difference, that the last polishing we did by hand on a heavy silk satin stretched over plate glass, using magnesium oxide paste. That is rather a tedious procedure. I have never succeeded in polishing a specimen in ten minutes, as the author has. It has always taken a longer time to obtain a satisfactorily polished surface.

MEMBER: About how long would it take to prepare a sample by the

[3] International Nickel Co., Bayonne, New Jersey.
[4] Bureau of Standards, Washington, D. C.

method the author has given? Also, what is the recommended size of the specimen, its cross-section, and what abrasive is best on the last wheel?

MR. SURLS: We find that we can polish a specimen easily in ten minutes, that is, providing the papers are all ready so that we can go right ahead with the polishing.

As to the size of the sample, I quite agree with Mr. Wood that this is an important factor. We use samples which are about ⅜ or ½ in. square. This size is much easier to polish than either larger or smaller ones. On several occasions I have attempted to polish the entire cross-section of a 1.2-in. arbitration test bar and although I did get a polish that was passable, it took much more time and was much more difficult to obtain.

In regard to the use of abrasives other than rouge on the last wheel, I have found that the rouge gives very satisfactory results and requires less skill and care than other abrasives that we have attempted to use. To obtain a satisfactory polish, it is necessary to use an abrasive which will cut cleanly across the surface without cold working the metal and smearing it over the graphite or without breaking up the graphite so that it may drop out of its cavities. A proper grade of rouge will cut rapidly and remove the scratches, left by the 400 mesh paper, in a very short time. Usually about one-half minute will be sufficient time on the final wheel.

MEMBER: To prevent this dislodging of graphite, what method is used in cleaning, if you do, the specimen before you etch it, that is, in removing the rouge which clings to it after the final operation? Do you wipe it or what do you do?

MR. SURLS: Our practice has been to wash the sample under a stream of water and dry it carefully. That seems to be all that is necessary.

# Porosity in Leaded Bronze Bushings

By A. W. Lorenz*

**Abstract**

*Porosity in cast products generally occurs as gas or blow holes or as shrinkage voids. One of the most common causes of blow holes is cold metal. Another cause is entrapment of gases due to the metal flow within the mold. The author conducted experiments to determine how metal flow affected the porosity of a certain type large bushing with which the foundry was having trouble. The results of that investigation showed that improper gating was the cause of the trouble since gating affected the metal flow within the mold. He also conducted some interesting experiments on mold washes and came to the conclusion that mold washes tend to promote porosity in heavy castings made from the type of metal under discussion. The author also investigated a condition of porosity due to metal used and states that this is the only instance in his experience where metal could be blamed definitely. He also describes the conclusions reached concerning the boiling of metal in a ladle. In this instance, boiling was due to dross on the sides of the ladle. The author also conducted some experiments to determine the effect of phosphorus and zinc on an alloy containing 80 per cent copper, 7 per cent tin and 13 per cent lead. After careful investigation, he found that over one ounce of phosphor-copper or 1 lb. of zinc per 100 lbs. of melt was sufficient to produce undesirable shrinkage in heavy sections. The author is of the opinion that the majority of shrinkage trouble is due to over-reduced metal.*

1. The material presented in this paper is derived from a series of investigations into the problem of porosity in bronze bushings containing from 12 to 25 per cent lead. Since the entire subject of porosity cannot be covered adequately in a paper of this type, the author has confined this paper to a description of several experiments in molding methods, which he believes may be of interest, and to a brief resumé of several investigations into melting practice.

2. Porosity in cast products, whether ferrous or nonferrous, is found in two commonly observed forms: (1) as gas or blow holes,

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* Deceased. The author of this paper was chief chemist and metallurgist for the Bucyrus-Erie Co., South Milwaukee, Wis.

Note: This paper was presented at a session on Nonferrous Founding at the 1934 Convention of the A.F.A.

and (2) as irregular shrinkage voids. If consideration is given to the subject of hole porosity, that type of defect may be classified further with respect to source as (1) holes formed by gases external to the metal and (2) holes formed by gases within the metal.

## HOLES CAUSED BY EXTERNAL GASES

3. Holes caused by gases external to the metal may include blow holes caused by mold conditions such as wet sand, poor venting, etc.; and those due to entrapment. Such entrapment may sometimes result from poor molding practice, but more often results from cold and sluggish metal.

4. Holes originating from mold conditions frequently may

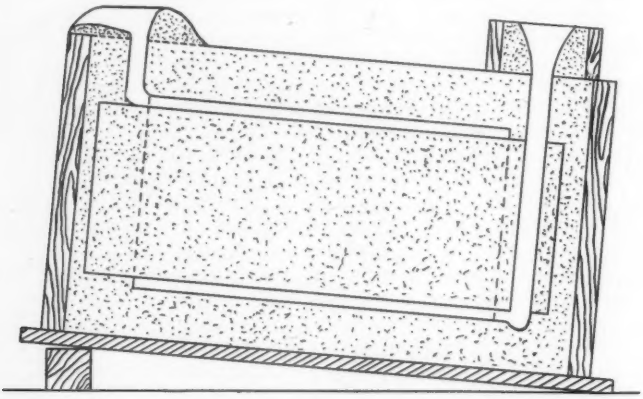

FIG. 1—MOLD FOR LEADED BRONZE BUSHING. THE BUSHING WEIGHED OVER 1000 LBS. AND SHOWED AN ACCUMULATION OF HOLES AND DIRT UNDER THE SKIN ABOUT 12 INS. ALONG THE COPE NEAR THE GATE END.

be recognized by their position, since they seldom permeate the entire casting. Furthermore, although no hard and fast rules can be established, they tend to be larger within a casting of given size and to show greater variation in size in any single casting, than do gas-holes originating within the metal.

5. One of the most common causes of blow-holes is cold metal, which, by reason of its sluggishness, entraps air or gases found within the mold. Such blow-holes will be scattered irregularly and will follow lines of metal flow. In some cases, they will be associated intimately with cold-shuts. That gives a clue to their cause. They are generally clean and bright and of variable size, ranging from pinholes to ¼-in. or even ½-in. in diameter. When an epidemic of

this trouble occurs, it will begin in small thin castings, from which, with increasing severity, it extends to castings of larger size.

## INVESTIGATES METAL CURRENTS

6. Gases often may be trapped due to the nature of metal flow within the mold. An interesting example is that illustrated by the large bushing mold shown in Fig. 1. These bushings, weighing over 1000 lbs., showed an accumulation of holes and dirt under the skin for a distance of about 12 ins. along the cope near the gate end. Since the mold was tilted about 6 inches as shown, the foundry foreman could see no reason why gas or air should be entrapped at this point. He had used several hundred pounds of metal as a run-off after the mold was filled, and felt that this should be sufficient to wash out any accumulations along the cope.

7. Believing that the direction of metal currents within the mold was a determining factor, a transparent celluloid mold was constructed, as shown in Fig. 2. This mold was 18 ins. in diameter and 36 ins. long. The ends consist of stepped wooden disks. The outer disks on each end are 18 ins. in diameter, while the inner disks are 16 ins. Sheets of transparent celluloid were wrapped over both the outer and inner disks. The celluloid was cemented to the wood all around at each end with "plastic wood." All celluloid joints were sealed by moistening with acetone. The annular space between the inner and outer shell thus was made water-tight and represented a mold cavity.

8. Holes were bored through one end to simulate gates located at various positions. When the holes were not used they were plugged with dowels. A hole in the opposite end, at the top, represented the run-off or riser. The down-gate was a piece of rubber tubing, connected at the upper end to a wooden "runner box." To observe the liquid flow within the "mold", water was admitted in a full stream through the runner box. A liberal amount of dyed sawdust was introduced with the water. Swirling of the sawdust clearly indicated the liquid motion within the mold.

## CAUSE OF GAS POCKETS DISCOVERED

9. Referring to Fig. 3, it was observed that with the gate located at the bottom and with the mold substantially raised at the overflow end, the water did not flow upward along the cope toward

the run-off, but formed eddy-currents which flowed backward along the cope, away from the run-off. This naturally would create a pocketing effect, and was a full explanation of the cause of gas pockets and holes in the castings.

10. By employing a second gate located in the cope, as shown in Fig. 4, the eddy currents were counteracted as the mold filled. The dotted lines show the liquid current just before the mold was filled completely, and the solid wavy line indicates the washing effect of the upper gate. This principle was applied in practice and successfully overcame the difficulties encountered with this type of casting.

11. Clean bright holes of uneven size sometimes are found near mold partings, especially where heavy fins are cut. They occur

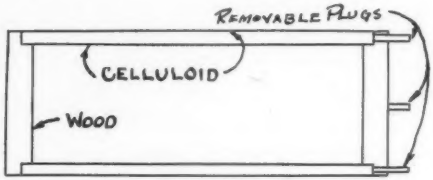


FIG. 2.

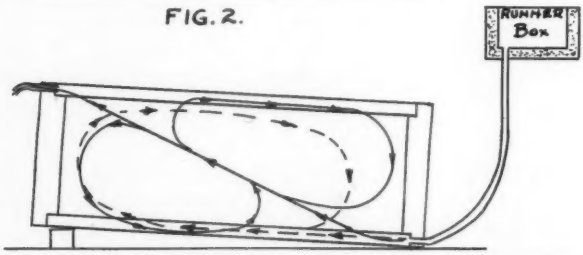


FIG. 3.

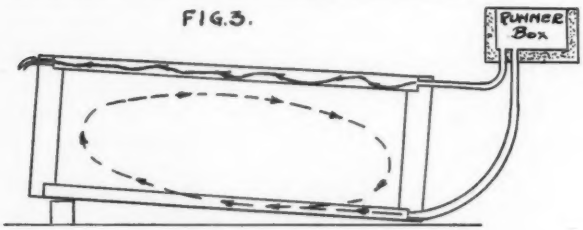


FIG. 4.

FIG. 2—APPARATUS, SIMULATING MOLD CONDITIONS, USED TO STUDY METAL CURRENTS. FIGS. 3 AND 4—DIRECTIONS OF METAL CURRENTS OBTAINED BY TWO DIFFERENT METHODS OF GATING. DOTTED LINES SHOW CURRENTS BEFORE THE MOLD IS FULL AND SOLID LINES SHOW CURRENTS AFTER THE MOLD IS FULL.

when air or steam generated in the parting expands so rapidly that it cannot escape through the sand and therefore is forced out through the metal. The trouble is especially prone to occur when the parting is washed and backed by dough rolls. Cold metal undoubtedly accentuates the condition.

## MOLD WASHES CAUSE DEFECTS

12. Washed mold faces always have a tendency to prevent the escape of air from the mold cavity. This tendency is not pro-

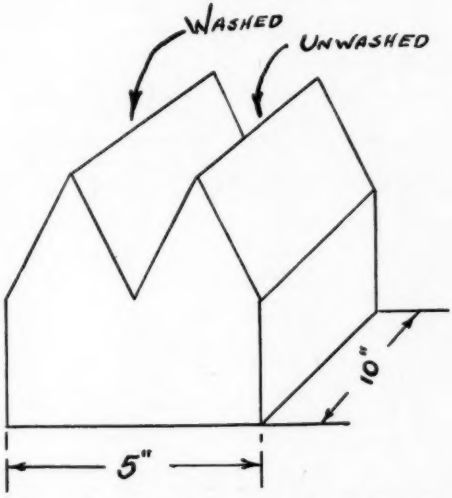


FIG. 5—PATTERN USED TO STUDY THE EFFECT OF MOLD WASHES. IN THIS TEST, ONE TOOTH WAS LEFT UNWASHED AND THE OTHER WAS WASHED.

nounced, but nevertheless it is present. To demonstrate this fact, a special pattern was cast, as shown in Fig. 5. In the mold, which was cast in the position shown, one tooth was washed with graphite and the other was left unwashed. The mold was dried thoroughly. The resultant casting, when sawed in half, disclosed fine pinholes at the apex of the blackened tooth, while the other was solid.

13. At this point it was suggested that holes might be formed from the interaction of carbonaceous materials with oxides from within the metal. To test this theory a mold containing four wedges, as shown in Fig. 6, was cast. Two wedges were washed with graphite. Into one of these wedges a substantial amount of litharge was

introduced as an oxidizing agent. Another wedge was coated with steel foundry silica wash, and the fourth was unwashed. It will be noted that no vents were provided, and that the parting was at the bottom. Consequently, all the air had to escape through the sand.

14. The unwashed wedge was sound throughout. The three washed wedges showed, to equal extent, a thin layer of fine holes under the top surface. Therefore, it is evident that, to a limited extent, mold washes retard the escape of mold gases. For this reason, the author prefers to avoid the use of washes on heavily finned partings. The test proved further that the pinholes were not formed by the interaction of carbonaceous matter with oxides within the metal since the mold in which silica wash was used showed the same thin layer of fine holes.

## GASES ORIGINATING WITHIN THE METAL

15. Probably no other subject is capable of arousing more

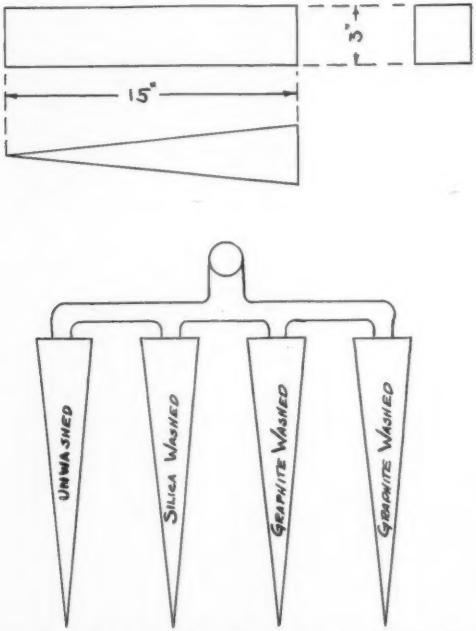


FIG. 6—METHOD USED TO STUDY THE INTERACTION OF CARBONACEOUS MATERIALS AND OXIDES WITHIN THE METAL.

discussion among foundrymen than that of unsoundness caused by oxidation or reduction phenomena originating within the metal.

16. So far as the author's experience is concerned, he has encountered only one experience with blow-holes or gas-holes, which he is willing to concede definitely was caused by metal conditions and that was only for a brief period of operation. This particular form of porosity is shown clearly in Fig. 7, which is reprinted from an article by Doughty[1*], but which nevertheless exactly reproduces the conditions which the author observed.

17. This condition is characterized by a plane or ring of small,

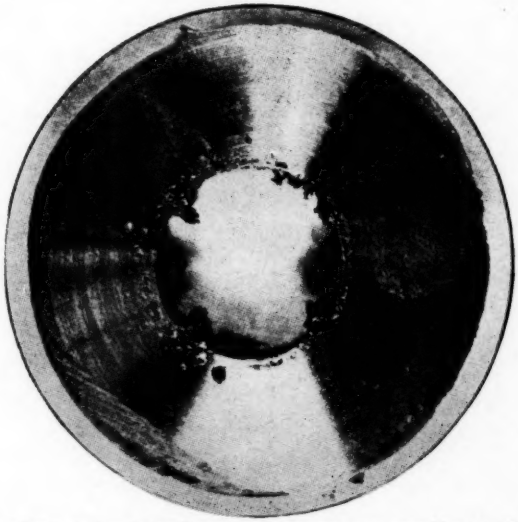

FIG. 7—A TYPE OF POROSITY CAUSED BY CONDITION OF THE METAL. (DOUGHTY)

fairly uniform-sized holes located in each instance at a distance of about ⅛ in. from any cored surface. Almost any foundryman at once would lay the trouble to the cores. Doughty described many tests carried out on the asumption that this was the case, but he finally was forced to conclude that the metal was oxidized. He claims to have overcome the difficulty by the addition of the unusual amount of 3 lbs. of phosphor-copper per 100 lbs. of melt.

18. A short time after reading of this work, the author encountered exactly the same trouble. Not being convinced of Doughty's conclusions, he determined to find what was wrong with

* The superior numbers refer to bibliography at the end of this paper.

the cores. Various core binders were tried without avail. The permeability of the core sand was increased without effect. For an extreme test, a core was made from new sand-blast sand and bonded with oil. Permeability of the core was 660. This sand was so open that the metal penetrated the core like a sponge. When the sponge was chipped away, and after the casting was machined, the familiar ring of holes 3/16 in. in from the normal surface of the casting was found.

### HOLES STILL EVIDENT

19. Having found, in the meantime, that we could make absolutely sound castings in green sand, we took a regular green sand mold, of Albany No. 1½ sand, and, after some difficulty, succeeded in drying it thoroughly in the oven. On machining the casting, holes were found ⅛ to 3/16 in. in from all surfaces. A companion mold in the green condition, cast from the same ladle, gave perfect castings.

20. After all our attempts had failed, we increased the phosphor additions to 1 lb. per 100 lbs. of metal, and secured a perfect casting. Realizing that this practice, if continued, would lead to other troubles, the melting practice was changed to permit more thorough deoxidation within the furnace. With this change, it was possible to revert to our usual practice of adding about one ounce of phosphor-copper per 100 lbs. of melt.

21. To the metallurgist, as well as the foundryman, it may seem somewhat radical to concede that oxidized metal is characterized by good pouring qualities in green sand, but not in dry sand. Nevertheless, this appears to be the case—provided the contention is accepted that the described condition is one of oxidation. Certainly, the remedies that were applied are those which invariably are associated with deoxidation.

22. Why the holes appear at such a uniform distance from a cored or dried surface, and why they do not appear at all in green sand, is a matter difficult to explain. Perhaps there is a critical cooling rate favorable to the liberation of gas. Subsequently, we cast some metal of the type mentioned into a mold made from sand which the molder claimed was almost too wet to work, and obtained a nearly perfect casting.

23. While the previously described condition is characterized by a band of holes adjacent to dry sand surfaces, it is presumed that oxidation in its more severe forms might cause holes throughout a casting. However, if the described condition is accepted as

one of incipient oxidation, then a means of key control is provided. That key control is merely keeping careful watch on heavy dry sand work.

24. While boiling of metal in the ladle is a topic which does not exactly fit into a discussion of porosity, nevertheless this phenomena is a cause of concern to many foundrymen because they believe that the metal is gassed and unsatisfactory for casting purposes.

## METAL BOILS IN THE LADLE

25. Having encountered this condition from time to time, it was thought that a dirty ladle might be responsible. To test this idea, a pot of metal was tapped from the furnace at 2400 deg. Fahr. This metal was phosphorized with one ounce of phosphor-copper per hundred pounds of metal, but the fluidity was greater than this small addition might indicate, both by reason of the high temperature, and because of melting conditions. The surface of the metal "broke" continually, and the small amount of visible slag was thin and mobile.

26. The metal boiled vigorously over the whole surface of the used pot, into which this metal was first tapped. After holding the metal in this pot only long enough to observe the boiling effect, the metal was transferred to a new crucible. Boiling stopped immediately. On pouring back into the original crucible, the boiling again commenced, and this condition was repeated as often as the metal was poured back and forth, until a temperature of 2050 deg. Fahr. was attained. At this temperature, the metal, which now only simmered around the edge of the pot, was poured into castings. The castings were solid.

27. The conclusion was that in this instance boiling in the ladle was due to dross adhering to the sides from a previous heat.

28. That experiment has been repeated at various times, and as far as the amount of boiling which exists at normal pouring temperatures is concerned, it does not seem to be injurious to the castings.

## SHRINKAGE EFFECT VARIES WITH METAL

29. In ferrous metals, shrinkage effects usually are concentrated in one or more relatively large shrinkage cavities, and are recognized easily. In bronzes, shrinkage frequently takes place in the form of intercrystalline voids or cracks, which may range in size from microscopic dimensions to ragged tears or fissures many

inches in length. These fractures are sometimes, though not always, darkly colored, ranging from copper-red to brown. Lead segregation also may be evident in the form of gray mottled patches.

30. These latter characteristics sometimes confuse foundrymen into believing that the described condition is brought about by "burnt metal" or by insufficient mixing. Nevertheless, the frequently visible dendritic skeletons and crystal formations leave no doubt as to the fundamental nature of the defect. Shrinkage in its incipient stages, such as is usually encountered in light castings, has been described thoroughly by Bolton and Wiegand[2, 3], but many foundrymen apparently have not recognized the similarity between incipient shrinkage and the more exaggerated forms described previously.

## PHOSPHORUS AND ZINC INFLUENCE SHRINKAGE

31. H. J. Roast[4], in a paper presented before the A.F.A. convention in 1933, discussed shrinkage conditions as brought about by excessive additions of silicon, aluminum and phosphorus. Several years ago the author conducted experiments along similar lines to determine the limiting amounts of phosphorus, or zinc which might be employed in mixes under the conditions existant in our shop. The particular composition under investigation was a bearing bronze containing 80 per cent copper, 7 per cent tin, and 13 per cent lead. The melting unit was a rocking-type electric furnace.

32. The experimental procedure consisted of operating with various selected mixes for periods of one week, with an observer stationed in the machine shop to record the condition of every casting. The thorough nature of these observations may be apparent from examination of the sample tally sheet reproduced in Fig. 8.

33. Records covering several thousand bushings and eight different mixes showed that over 1 ounce phosphor-copper or 1 lb. zinc per hundred pounds of melt was sufficient to produce undesirable shrinkage in heavy sections. These figures apply only to a definite practice, and should not be taken as absolute. They may be affected considerably by changes in molding practice and other factors. It may be stated that the indirect arc furnace is capable of considerable manipulation as far as melting conditions are concerned. Excessive shrinkage may be apparent even with normal amounts of deoxidizer, if furnace conditions are strongly reducing.

34. Except perhaps for occasional shrinkage failures brought about by the extreme sluggishness of oxidized metal poured at too low a temperature, the author believes that the great bulk of shrinkage trouble is caused by over-reduction, or similarly, over-deoxidation; and that, within reasonable bounds, the influence of one variable may be counteracted by another to produce a desirable equilibrium. It always may not be possible or advisable to assign a specific cause for a shrinkage failure, but if the symptoms are

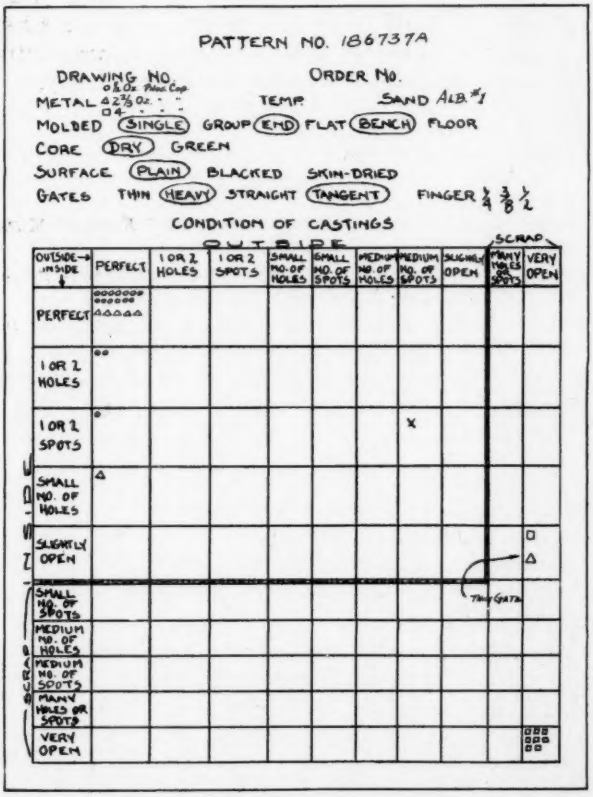


FIG. 8—CHART USED TO RECORD OBSERVATIONS ON CONDITION OF BEARING BRONZE CASTINGS AFTER MACHINING.

recognized in their general aspects, the foundryman has recourse to a number of methods of handling the situation.

35. It is in the recognition and classification of symptoms that the foundryman needs greatest assistance. Volumes have been written regarding the cures for various defects, but each foundryman operates under a set of conditions peculiar to his own shop. What is found to be one man's cure may be another man's poison. If the foundryman possesses an infallible method of diagnosis, his troubles will be practically over.

## CONCLUSION

36. In conclusion, it is the author's belief that to a limited extent at least, it should be possible to develop such a schematic system of diagnosis, and that if a competent body were entrusted with this task, it would be of great benefit to the industry.

## REFERENCES

[1] Doughty, E., "*A Cause of Porosity in Leaded Bronze*," METALS & ALLOYS, vol. 2, no. 4, October 1931, p. 181.

[2] Bolton, J. W. and Wiegand, S. A., "*Incipient Shrinkage in Some Nonferrous Alloys*," TECHNICAL PUBLICATION No. 163, A.I.M.E.

[3] Bolton, J. W. and Wiegand, S. A., "*Effect of Oxidation and Certain Impurities in Bronze*," TECHNICAL PUBLICATION No. 281, A.I.M.E.

[4] Roast, H. J., "*A Practical Foundry Test on the Effect of Phosphorus, Aluminum, and Silicon on Leaded Bronze*," TRANSACTIONS A.F.A. 1933, p. 82.

# Symposium—
# Porosity in Steel Castings

## Preparation of Steel to Avoid Porosity in Castings

By C. E. Sims*, East Chicago, Ind.

**Abstract**

*The author gives three main sources for porosity: condition of the metal, condition of the mold material, and construction of the mold. This paper is concerned only with the preparation of the metal. Gases which occur in steel are stated to be carbon monoxide and carbon dioxide, present only as reaction products, and hydrogen and nitrogen, which are soluble as hydride and nitride, respectively. The author explains the role played by equilibria and surface tension. He states that the porosity problem resolves itself to (1) reducing dissolved gases as much as possible, and (2) producing the conditions most favorable for retaining in solid solution those gases that could not be eliminated. Conditions favoring the first step, or low gas content, are a long, vigorous boil, thorough oxidation, low residual silicon and manganese, moderate temperatures, late oxidation, and no increase in temperature after deoxidation. Conditions favoring retention of gases in solid solution are thorough deoxidation and minimum exposure after deoxidation. The author states that control through selection of charge and control of atmosphere seems both impractical and unnecessary.*

1. The evil genius of the whole casting industry is unquestionably that malicious sprite that causes porosity and blow-holes in castings. To exorcise this sprite has been the aim of untold labors by founders from the dawn of history. This does not mean that castings cannot be, and are not being, made free from porosity and blow-holes. On the contrary, the greater bulk of castings are sound and relatively free from such defects; but porosity has an annoying way of coming and going and is not under satisfactory control.

* Assistant Director of Research, American Steel Foundries.

Note: This paper was presented and discussed at a session on Porosity in Steel Castings held at the 1934 Convention of A.F.A. The discussion of this paper will be found beginning on page 394, where the discussion of the four papers presented at this meeting is reproduced.

2. Our knowledge has been too largely empirical and our remedies have been mostly of the cut-and-try variety. Some of the opinions regarding porosity could hardly be more fantastical if they were credited to the occult. Empiricism in this case has failed: the problem is too complex. We must now look to a greater knowledge and application of the fundamental concepts of the gas-metal relations for a solution.

## SOURCES OF POROSITY

3. Three principal sources can be assigned for the origin of porosity: namely, condition of the metal, condition of the sand or other mold materials, and construction of the mold. Method of pouring is undoubtedly a contributing factor in many cases but is not here assigned as a principal source. So far as possible, this discussion will deal only with the first source—the preparation of the metal—and will be further confined to steel.

4. The problem of porosity revolves around the fact that steel, in common with most other metals, shows a sudden decrease in its ability to hold gases in solution when the freezing point is reached. If molten steel contains sufficient gas in solution, there will be an evolution of gas during freezing and part of this gas will be trapped within the body of freezing steel.

## NATURE OF SOLUBILITY

5. In using the word "solution" as applied to gases in steel, it is used in its broadest sense, as meaning the retention of gases in the unfree state. Too little is known definitely about the mechanism of such solution, and whether it is due to "simple solubility," "chemical solubility," absorption where loose quasi-compounds are formed, or some electronic phenomenon as proposed by Lewis[1]*, (which rates a metal's ability to dissolve gas on its ability to dissociate the gas), is not known. Gottschalk and Dean[2] argue convincingly that the simple solubility of gases in metals must be close to zero. Certainly molten metal solutions of gas do not follow the laws of simple solutions as formulated for other liquids, such as aqueous solutions. Henry's law, which states that the solubility of a gas at a given temperature is proportional to the pressure of that gas above the solution, is openly flouted.

6. The law of Sieverts,[3] which calls for a variation of the solubility in accord with the square root of the pressure, is more

* Superior numbers indicate references at the end of the paper.

nearly correct for most gas-metal solutions. Simple aqueous solutions of gas have a negative temperature coefficient: that is, the solubility decreases with rise in temperature. Metal solutions, on the other hand, have a positive coefficient, which causes the solubility to increase with rise in temperature. Moreover, this positive coefficient for molten metals is very much larger than the negative coefficient for known simple solutions.

7. Sieverts'[4] experiments indicate that the inert gases, such as argon, helium, neon, etc., do not dissolve in metals. A number of investigators report the complete insolubility of hydrogen and nitrogen in certain metals. On the other hand, Archer[5] found that when magnesium was melted under argon gas, gassy metal was obtained; whereas it was sound when melted under helium. Commercial gases were used in both cases, and there is the possibility that impurities may have caused the difference.

8. The weight of evidence leans heavily to the probability of a chemical solution of some kind for gas in metal. The fact that the solubility of gases in molten metals is so extremely sensitive to slight changes in the chemical composition is easily explained by the theory of chemical solubility, but would be most difficult to explain on the basis of simple solubility.

## Results Do Not Agree

9. Although a vast amount of work has been done by careful and experienced investigators on quantitative determinations of the solubility of gases in metals, there is a remarkable lack of agreement as to results. A number of reasons may be advanced as possible explanations for these discrepancies. Imperfections in the delicate and complex apparatus used for the determinations may account for some of them. In dealing with such extremely small amounts, as in the analysis of gas in metal, a slight error may lead to a relatively large discrepancy. For instance, as quoted from Gottschalk and Dean,[2] "Two recent values for the solubility of hydrogen in silver at 800 degrees Cent. are 0.45 cc. (Steacie and Johnson) and 0.73 cc. (Sieverts) per 100 grams of silver, or 4 and 6.5 in 10 million parts by weight, respectively, or 1 atom of hydrogen respectively in 21,000 and 13,000 atoms of silver." It is only because of the relatively enormous volumes that gases have in comparison with their masses that makes it possible to work with such small quantities.

10. A more probable cause of the discrepancies is that certain

aspects of the little known gas-metal relationships have not been properly considered. The effect of minute quantities of impurities, uncertainties as to whether saturation has been reached, and loss of gas between the time of preparation and analysis of sample would all influence the results.

11. However, while we must accept, for the present, the postulate that the solubility of gases in metals is principally due to a chemical solubility or the formation of some kind of addition compound, there is the strong probability that there is also a slight but significant simple solubility as well. This complexity of solubility makes the problem of degasification or the control of porosity extremely more difficult than if only a simple physical solubility were involved.

12. The gases that are of concern in steel making include oxygen, carbon monoxide, carbon dioxide, hydrogen, and nitrogen. All of these gases are practically always evolved during the vacuum fusion analysis of steel. Small quantities of water vapor and gaseous hydrocarbons are also often found.

13. Of these gases, the first three, namely, oxygen ($O_2$), carbon monoxide (CO), and carbon dioxide ($CO_2$), have an intimate interrelationship through the reactions of the system iron-carbon-oxygen, and these three elements are always to be found in steel.

## OXYGEN

14. The solubility of oxygen ($O_2$) in iron or steel is the solubility of iron oxide (FeO). This is especially evident in very hot or molten steel, where the high affinity of iron for oxygen precludes the possibility of more than the minutest quantities of elemental oxygen being present. Of course, some oxygen will always be present as oxides of foreign metals and metalloids, as for example: MnO, $Al_2O_3$, and $SiO_2$.

15. The solubility of oxygen in iron was determined first, both qualitatively and quantitatively by Tritton and Hanson,[6] who reported a saturation value at 1535 degrees Cent. (2795 degrees Fahr.) of 0.21 per cent, which is equivalent to 0.94 per cent FeO.

16. Herty and Gaines[7] determined the relationship between temperature and the solubility of FeO in iron. Their results check with those of Tritton and Hanson at 1535 degrees Cent. (2795 degrees Fahr.) and show that the solubility increases with temperature as a straight-line function until at 1700 degrees Cent. (3090 degrees Fahr.) there is 2 per cent FeO present.

17. These figures, of course, apply to nearly pure iron with a slag consisting principally of FeO. Such concentrations would never be reached in practice. Actually, the amount of FeO in a bath of steel is dependent on the FeO content of the slag. The iron oxide always tends to divide itself between the slag and metal, according to a definite distribution ratio that varies with the conditions. Herty has shown that this distribution ratio is greatly affected by temperature.

18. Ziegler[8] reports that the solubility of oxygen in solid iron is negligible below the critical temperature, but that above 900 degrees Cent. (1650 degrees Fahr.) it increases rapidly with temperature and reaches a maximum at 1000 degrees Cent. (1830 degrees Fahr.) of 0.10 per cent, corresponding to 0.45 per cent FeO.

## SOLUBILITY AFFECTED BY DEOXIDIZERS

19. As is well known, the solubility of oxygen in molten steel is enormously affected by the presence of other elements, principally the so-called deoxidizers, with which it reacts to form more or less insoluble oxides or other reaction products. Typical of these is the familiar reaction $FeO + C \rightarrow Fe + CO$. Theoretically, this reaction should proceed until the carbon and FeO reach definite proportions, representing equilibrium for the reaction.

20. The constant for this equilibrium expressed as the product (per cent FeO) $\times$ (per cent C) has been experimentally determined by Kinzel and Egan[9] as 0.0005. Experimental and calculated values have been reported elsewhere which vary all the way from this figure to that of 0.011 at 1620 degrees Cent. (2950 degrees Fahr.), found by Vacher and Hamilton.[10] From the free energy values, Chipman[11] calculated the constant to be 0.005 at 1620 degrees Cent. (2950 degrees Fahr.). Taking the last figure for example: when the carbon is 0.20 per cent, it should be possible to have only 0.025 per cent FeO in liquid steel at 1620 degrees Cent. (2950 degrees Fahr.). Practically, we know that we can have more FeO for reasons which will be given in detail later.

21. Other typical reactions are—

$$FeO + Mn \rightarrow Fe + MnO.$$
$$2FeO + Si \rightarrow 2Fe + SiO_2.$$
$$3FeO + 2Al \rightarrow 3Fe + Al_2O_3.$$

22. Chipman[11] has calculated equilibrium values for all of these reactions. The manganese reaction is complicated by the

solubility of MnO. These values at three different temperatures are given in Table 1.

23. It is readily seen from Table 1 that manganese alone is a poor deoxidizer, that aluminum is greatly more effective than silicon, and that all are more efficient deoxidizers at low than at high temperatures.

## CARBON MONOXIDE AND CARBON DIOXIDE

24. There is some uncertainty regarding the solubility of carbon monoxide and carbon dioxide (CO and $CO_2$) in steel. They are always to be found in the gases evolved from steel, either when solidifying or when subjected to vacuum treatment, either hot or cold. However, Klinger,[12] as reported in the Fourth Report on the

**Table 1**

EQUILIBRIUM CONSTANTS OF SOME COMMON REACTIONS IN STEEL

| | | At Temp. Of | | |
|---|---|---|---|---|
| | | 1500° C. 2730° F. | 1600° C. 2910° F. | 1700° C. 3090° F. |
| $\frac{\%\ MnO}{\%\ FeO \times \%\ Mn}$ | = | 4.55 | 2.30 | 1.25 |
| $(\%\ FeO)^2 \times \%\ Si$ | = | $1.9 \times 10^{-5}$ | $1.5 \times 10^{-4}$ | $1.0 \times 10^{-3}$ |
| $(\%\ FeO)^2 \times (\%\ Al)^2$ | = | $1 \times 10^{-14}$ | $7 \times 10^{-13}$ | $4 \times 10^{-11}$ |

"Heterogeneity of Steel Ingots,[13] after an exhaustive study of the gases evolved from solidifying steel, reached the conclusion that CO and $CO_2$ were merely reaction products of the reaction $FeO + C \rightarrow Fe + CO$. These gases are not found when using the cold decomposition methods with iodine, and their solubility in steel must be denied.

25. The work of Kinzel and Egan[9] on the equilibrium of the system iron oxide-carbon in molten iron, confirms this viewpoint and establishes the fact that CO and $CO_2$ are not appreciably soluble in molten steel.

## HYDROGEN

26. The fact of the solubility of hydrogen ($H_2$) in steel has been thoroughly established by a number of investigators. Sieverts[14] made quantitative determinations of its solubility at various temperatures and produced a curve which is shown in Fig. 1. It will be noted that there is a sharp break in the curve at the melting point.

27. Ziegler[15] found no hydrogen in samples of steel prepared in the laboratory but found it in all commercial samples.

28. While the effect of most of the elements common to steel on the solubility of hydrogen is an unknown quantity, it is a well established fact that oxygen has a large influence on the solubility, and also on the action of the hydrogen that is retained. This latter influence works through the reversible reaction $H_2 + FeO \leftrightarrows Fe + H_2O$. Hydrogen gas may be used to deoxidize steel but not without saturating the latter with hydrogen. On the other hand, oxygen can remove excessive amounts of hydrogen. Neither can entirely eliminate the other.

29. Deoxidizers, like manganese, silicon, and aluminum, are popularly credited with the ability to increase the solubility of hydrogen in steel by their presence. There seems to be no direct proof of this, however; and their evident effect may be due to their influence on the oxygen content.

## Nitrogen

30. There is also considerable evidence to prove the solubility of nitrogen in steel. Svechnicov[16] reports that through the nitrifying of pure iron by means of ammonia, it is possible to obtain iron nitride ($Fe_2N$) with 11.1 per cent nitrogen. The best condition for this reaction is at about 450 degrees Cent. (840 degrees Fahr.).

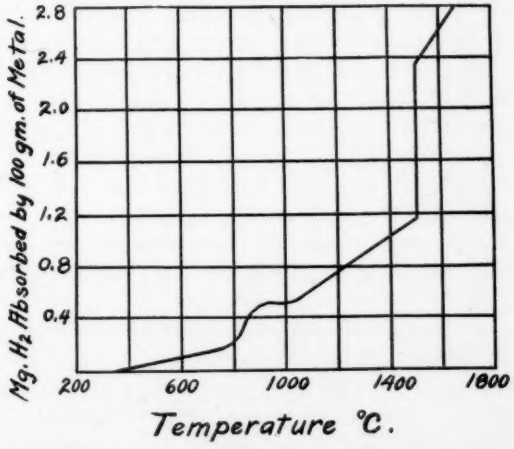


Fig. 1. The Effect of Temperature on the Solubility of Hydrogen in Iron (Sieverts).

With increasing temperature, the nitride decomposes and at 1200 degrees Cent. (2190 degrees Fahr.) all the nitrogen is removed.

31. Elemental nitrogen apparently does not dissolve in solid iron or steel but dissolves readily in molten steel. Strauss[17] reports 0.03 per cent to 0.04 per cent as the upper limit for nitrogen ($N_2$) in molten iron, although Dean, Day and Gregg[18] report having introduced 0.07 per cent nitrogen by melting in air. However, commercial steels never contain any such quantity. Bessemer and electric furnace steels are apt to contain the most nitrogen and will have from 0.010 per cent to 0.024 per cent. Open hearth steels contain from 0.003 per cent to 0.008 per cent nitrogen, while crucible steels have but 0.0005 per cent to 0.002 per cent. The nitrogen absorbed by molten steel forms a stable nitride, which is not easily decomposed.

32. From a theoretical standpoint, Dean[19] has calculated that the absorption of nitrogen by pure iron could not be over 0.01 per cent and probably is less than .005 per cent. Any amount present over this quantity is probably due to the presence of impurities. There is considerable evidence that impurities, such as manganese and more especially silicon, have a profound influence on the solubility of nitrogen. Silicon itself absorbs nitrogen avidly at steel making temperatures. Dean[19] believes the evidence points to silicon as the chief offender in introducing nitrogen into steel.

### COKE RECARBURIZATION INCREASED NITROGEN

33. Experiments by Wust and Duhr[20] on duplex steel which was started in an open hearth and finished in an induction furnace show a sharp increase in nitrogen immediately following recarburization with coke. In two heats reported, nitrogen increased in one from 0.0025 per cent to 0.0098 per cent in 10 minutes, while in the other, it increased from 0.0028 per cent to 0.013 per cent in less than two hours. Nitrogen had shown a loss during the preceding 5 hours in each heat. The nitrogen may have merely been in the coke, but it is more likely that the increase is due to a change in the degree of oxidation of the steel. The highly oxidized steel can contain only about 0.002 per cent nitrogen, but as soon as the oxygen content is reduced, the nitrogen content increases. Perhaps this explains the action of silicon, manganese, and aluminum in apparently increasing the solubility of nitrogen in steel. The presence of these elements acts against the presence of oxygen.

## The Role of Equilibria and Surface Tension

34. In common with most chemical reactions, few metallurgical reactions go to completion. There is an equilibrium constant that sets a definite ultimate limit. But what is more important, is that reactions seldom reach true equilibrium. The law of mass action far overbalances the importance of stoichiometric proportions.

35. Some reactions do not attain equilibrium because of the time factor. Steel making is a dynamic process and things must be kept moving for economic reasons. At other times, a definite physical barrier may arise to stop a reaction short of equilibrium.

36. Such a situation is present in the familiar reaction $FeO + C \rightarrow Fe + CO$, which is the reaction of decarburization and which gives rise to the carbon boil. As noted earlier, the equilibrium constant for this reaction K = (per cent Fe) × (per cent C) is somewhere in the neighborhood of 0.0005 to 0.005. As a matter of everyday experience, it is known that the boil often ceases when this product is as high as 0.03, or in other words, when there is from 6 to 60 times as much FeO present as would be possible under equilibrium conditions for a given carbon content. Under these conditions there exists an apparent equilibrium, as evidenced by the absence of any action.

37. The explanation for this as advanced by Gaines[21] is "— that a large excess of FeO is necessary in order that the CO may develop sufficient pressure to form a gas bubble. This is due to the tremendous compressive force of the iron on the minute bubble of gas. This pressure is a result, not of the ferrostatic head, but of the surface tension of the iron itself, which is very large." This makes it very difficult for a bubble to start, but once started, gas diffuses into it rapidly from the surrounding liquid.

38. Another example is the reaction $2H_2 + O_2 \rightarrow 2H_2O$. This reaction, if considered in the gaseous phase, proceeds rapidly and rather completely from left to right. But where the oxygen and hydrogen are present in a molten metal, as oxide and hydride, respectively, it requires a large excess of available oxygen to remove the hydrogen as the gaseous product $H_2O$.

39. The surface tension barrier to bubble formation presents a number of ramifications. For instance, Bircumshaw[22] found that he could not pump off the hydrogen in molten aluminum by vacuum treatment for 114 hours. On the other hand, it has been found that hydrogen can be removed from both aluminum and copper by

bubbling a neutral gas, such as nitrogen, through the molten metal.

40. This explains the value of the carbon boil as a degasifier for steel. According to the law of Sieverts, the solubility of gas in metal varies as the square root of the partial pressure of that gas in the atmosphere adjacent to the metal. Theoretically, all that would be necessary to rid a molten metal of dissolved gas would be to provide it with an atmosphere free from that gas Practically, this would be an endless process because the escape of the gas would all have to be at the surface. Take the case of a steel bath containing hydrogen. During the carbon boil, the bubbles of CO gas formed have a partial pressure of zero for hydrogen at the time of formation. For this reason hydrogen will immediately diffuse into them. Naturally each bubble would contain but a small proportion of hydrogen, but with the millions of bubbles being formed throughout the boil, there is opportunity for the bulk of the hydrogen or nitrogen to be removed.

41. As was apparent from the data given earlier on the equilibrium constants of the various deoxidizers, temperature plays a very important part in both the absolute and relative concentrations of elements other than iron in a bath of molten steel. For instance, at high temperatures, not only is the solubility of FeO increased but also a higher concentration is necessary to oxidize carbon at a given content. At low temperatures, just after a charge of steel is melted, first silicon and then manganese is oxidized almost quantitatively by additions of FeO before any appreciable amount of carbon is eliminated. Increasing temperatures tend to reverse this condition; and when the temperature is high enough, silicon will be retained, while carbon is oxidized, or, in the absence of silicon in the steel, carbon will reduce it from the slag unless the latter is too basic. In Bessemer converters, where the temperature sometimes runs very high, it has been possible to oxidize the carbon while retaining as high as 1 per cent silicon.

## SOURCES OF GASES IN STEEL

42. Of the gases which at times cause trouble in steel, it has been shown that CO and $CO_2$ are reaction products of C and FeO. Although it is sometimes introduced physically by certain conditions that are set up in a mold, $H_2O$ is also principally a reaction product.

43. Some hydrogen and nitrogen already is contained in the pig iron and scrap that constitute the furnace charge. Also, the

ferro-alloys used in deoxidizing are known to contain both these gases.

44. The atmosphere of an open hearth furnace is always rich in nitrogen and water vapor, and usually contains some free hydrogen. Water vapor is oxidizing to hot steel, and hydrogen is liberated by the reaction $H_2O + Fe \rightarrow H_2 + FeO$. There is no flow of combustion gases through an electric furnace, and the atmosphere should ostensibly be freer from hydrogen and nitrogen. Nitrogen will always be present, however; and considerable quantities of a hydrated oxide, known as rust, provide a potential source of hydrogen. There is unquestionably some absorption of both hydrogen and nitrogen at the high temperatures preceding and during melting, but this has not yet been determined quantitatively.

45. When the steel is melted and is covered by a slag, the chances for further gas absorption might seem to be nil. The gas content of slags (except, of course, for oxygen) is entirely an unknown quantity, yet there is room for at least a strong suspicion that slags may act as gas carriers. Take for instance the most promising case: that of a basic electric furnace slag containing carbide. It is perfectly logical to suppose that it might also contain calcium cyanamide.

46. And last, but not least, is the effect of contact with the air and mold-gases during tapping and pouring.

## Significant Examples

47. A rimming steel is the most common example of a porous steel, made purposely so to achieve a definite end. The principal gas evolved during the freezing of a rimming ingot and the only gas desired is CO. The evolution of CO is due to the familiar reaction $FeO + C \rightarrow Fe + CO$, suddenly made more active by a shift in the equilibrium constant, which, in turn, is brought about by the rapidly decreasing temperature. This reaction can be rather nicely controlled by judicious use of deoxidizers, such as aluminum. This regulation of the FeO content modulates the violence of the effervescence and thus determines whether the gas-holes shall be near the skin of the ingot or deep seated.

48. But when the steel contains an excess of hydrogen, it almost invariably appears as undesirable skin-holes in the ingot. These hydrogen holes cannot be controlled with deoxidizers, and can be prevented only when sufficient deoxidizer is added to produce

a piping ingot, or in other words, to produce a deoxidized or "killed" steel.

49. It has been shown, however, that a sufficiently vigorous boil will carry off enough hydrogen to prevent these skin-holes. A high residual manganese (Mn), say, above 0.15 per cent, greatly increases the danger of skin-holes, and the charge is purposely kept low in this element, usually about 0.20 per cent. The action here is probably not a direct effect of Mn, but a high residual Mn reduces the oxygen content of the steel and causes a more gentle boil.

50. In acid electric furnace practice it has been amply demonstrated that a heat, melted low in carbon and finished without a boil, will be so gassy as to almost effervesce in the molds, and no amount of deoxidizer, aluminum included, will make it sound. A high residual silicon, or conditions that will cause reduction of silicon from the slag, set the stage for gassy steel. The obvious remedy is a higher degree of oxidation.

### EFFECT OF OXYGEN ON SOLUTION OF HYDROGEN

51. Personally conducted laboratory experiments in a high frequency induction furnace have shown that a charge of steel when melted and finished by deoxidation with ferromanganese and ferrosilicon in a certain way will yield a sound casting. Another charge handled in just the same way, except that a stream of hydrogen is directed against the bare surface from a partially submerged tube, before it is deoxidized, will still yield a sound casting. If, however, the procedure be changed so that the stream of hydrogen is introduced after deoxidation, the resulting casting will have more void than solid.

52. The presence of the oxygen in the first case prevented the solution of the hydrogen, or perhaps oxidized it as fast as it dissolved. Eventually, of course, all the oxygen would have been used up and the hydrogen would then have gone into solution.

53. "It has been demonstrated[13] that liquid copper, containing comparatively large quantities of hydrogen, can be cast into ingots without the formation of blow-holes, provided that the necessary precautions are taken to protect the metal from becoming contaminated with oxygen, either before or during casting. If, however, the same metal is allowed to absorb oxygen during casting, a very large number of blow-holes are formed in the ingot." In the absence of oxygen, the surface tension prevents the initial

formation of hydrogen bubbles. With oxygen present, the falling temperature causes a reaction with hydrogen to form water vapor. This latter being quite insoluble, with resultant high vapor pressure, forms small bubbles into which the hydrogen rapidly diffuses.

54. The action in steel is entirely analogous. With comparatively small quantities of hydrogen, a steel will solidify porous if not sufficiently deoxidized, *i. e.*, if the oxygen content is not brought low enough to prevent a reaction with the hydrogen. As an indication of what is meant by small quantities, Merica[23] has calculated that the presence of 0.0002 per cent hydrogen in free form in a casting will render it so porous as to be useless. As the hydrogen content increases, a correspondingly smaller concentration of oxygen is required to prevent reaction. It has been shown that silicon will not completely deoxidize steel, and that explains why it is sometimes necessary to use a stronger deoxidizer, such as aluminum, to prevent porosity. When porosity is thus prevented, the hydrogen remains as a supersaturated solid solution. However, if the degree of supersaturation is enough so that the pressure exceeds the surface tension of the steel, hydrogen will be evolved, and aluminum is powerless to stop it.

55. Most of the comments regarding hydrogen, with the exception of its reaction with oxygen, apply similarly to the action of nitrogen.

56. There are, of course, extraneous influences that will cause porosity, as for instance, migrant mold gases. A little water vapor introduced from this source might easily have the same effect as water vapor produced by internal reaction except that its action will be local. But as this is the subject of another paper, it will not be considered here except as to suggest that the greater the margin of safety against spontaneous evolution of gas in the steel, the less are the chances that migrant gases will cause porosity.

57. Experiments made in an induction furnace have led to the following observations. A heat of steel that would otherwise give a sound non-porous casting, will yield a porous casting, if poured over a green spout that causes it to "boil" from the water vapor given off. Steel can be safely superheated to a considerable degree before deoxidation, but the same amount of superheating after deoxidation is apt to result in porosity. Generally speaking, heats made without excessive gas content and deoxidized with manganese and silicon will be porous if the silicon is below about 0.25 per cent and sound if the silicon is higher.

58. Although there is no intention to make 0.25 per cent silicon an arbitrary minimum, experience has shown that under average conditions it is dangerous to go below that range in casting steel. The actual danger point will vary with other conditions, and in practice, a safe margin will be used. The first gas to be evolved with a decreasing silicon content is probably $H_2O$ rather than CO. Experience with rimming steel indicates that silicon in quantities of more than a few hundredths of a per cent seriously affects its rimming qualities. It is probable that CO can be discounted entirely as a primary factor in causing porosity, considering the silicon contents normally used in casting steel. Nevertheless, for reasons already given, when gas evolution is once started, the evolved gases would most certainly contain CO.

## SUMMARY

59. The "simple solubility" of gases in metals is extremely low. Gases in metals occur in "chemical solution" as oxides, hydrides, nitrides, etc.

60. CO and $CO_2$ are insoluble in steel and occur only as reaction products.

61. Hydrogen and nitrogen are both soluble in liquid steel as hydride and nitride, respectively.

62. The solubility of hydrogen and nitrogen is affected by the oxygen content.

63. The effect of deoxidizers on the solubility of hydrogen and nitrogen is due to their effect on the free oxygen content.

64. The resistance to bubble formation, caused by the high surface tension of steel, plays a very important part in the retention of gases.

65. This surface tension is overcome, and gas evolution takes place in the presence of bubbles of a neutral gas.

66. Although not offered as a positive conclusion, it seems logical to regard all "dead" or "killed" steels at their freezing point as containing gases in varying degrees of supersaturation. These gases under favorable conditions will be retained in solid solution but are potentially capable of causing porosity.

67. The porosity problem resolves itself to (1) reducing dissolved gases to the lowest possible content, and (2) producing the conditions most favorable for retaining in solid solution those gases that could not be eliminated.

68. Conditions favoring low gas content:

(1) Long, vigorous boil.
(2) Thorough oxidation.
(3) Low residual silicon and manganese.
(4) Moderate temperatures.
(5) No increase in temperature after deoxidation.
(6) Late deoxidation.

69. Conditions favoring retention of gases in solid solution during freezing:

(1) Thorough deoxidation.
(2) Minimum exposure after deoxidation.

70. Control through selection of charge and control of atmosphere at present seems both impractical and unnecessary.

71. More fundamental data on the gas-metal relations are urgently needed.

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*(Discussion of this paper will be found beginning on page 394.)*

# The Relation of Molds and Cores to Porosity in Steel Castings

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**Abstract**

*In discussing the effect of the mold and cores on porosity in steel castings, the author points out that the sand from which molds are made influences that defect considerable. In sands made from silica sand and bonding materials, the author shows that the characteristics of both the sand and the bonding materials influence the solidity of the casting. He outlines the properties of sands for green, skin-dried and dry sand molding and points out that the expansion of the interspacial atmosphere and the gases given off by the binders are two causes of porosity. He also states that the prevention of porosity in steel castings is an individual foundry problem. He discusses the properties of binders and explains the effects of various constituents of molding sands in various types of molding. He stresses the importance of the permeability of backing sands and explains why such sands should be higher in permeability than the facing sands. The functions of a good sand reclaiming system are discussed as is the question of new versus reclaimed sand for facings. The effect of various systems of molding on porosity and the effect of flask and jacket equipment are discussed in relation to the promotion of porosity. The author urges the use of specially prepared gate cores as a remedy for certain types of porosity and explains how they are made and how molding procedure can be changed to make use of them. He blames some types of porosity on improper gating and gating materials. The latter portion of the paper is devoted to a discussion of the effects that cores and materials used in their manufacture have in the promotion of porosity.*

1. Those forms of unsoundness in steel castings which are commonly described as porosity, most generally result from some

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NOTE: This paper was presented and discussed at a session on Porosity in Steel Castings held at the 1934 Convention of A.F.A. The discussion of this paper will be found beginning on page 394, where the discussion of the four papers presented at this meeting is reproduced.

deficiency of the molding material. This broad statement is by no means intended to convey the idea that steel castings are regularly afflicted with porosity as a result of the inadequacies of either molds or cores, but in the following pages, it is the author's intention to discuss the effect of certain deficiencies which may, through lack of proper safeguards, tend to promote one or more of the various defects generically described as porosity.

2. The porosity to be discussed in this paper is definitely to be limited to the type or types originating from the mold or from mold deficiencies. Largely, such porosity is exhibited as "gas holes" which are either the result of gas injected into the metal from the mold or gas released from solution in the steel because of the presumed physical action of entangled grains of sand.

3. It is conceded that there is a greater liability to this form of defect in green sand practice and in skin dried practice than exists in dry sand practice and it therefore becomes a legitimate postulate that water may be to a large extent responsible for the majority of the porosity in castings. This postulate also holds in respect to dry sand practice; a dried mold is never really free from water if clay is used as the bonding medium because the associated water of the fireclay is not evolved in the mold drying operation.

4. Spherical grain shape and uniform grain size might appear to be ideal attributes in the basic silica sand which is used, but it is doubtful whether such an assumption is safe in practice. As a matter of fact, it is the author's opinion that, in the production of both molds and cores, a mixture of basis sands of two well-defined and different grain size produces the best results. Particularly is this the case when jolt ramming is employed to produce either molds or cores. This definition carries its own practical limit of application because jolt ramming is not generally employed on deep castings.

5. Grain shape is particularly important in relation to the system of ramming employed and it is safe to say that sands of an angular type, such as are usually employed in dry sand practice, do not flow as freely and uniformly as do sands of a rounded grain type. This failure to flow may result, in mechanical ramming, in irregular strength and irregular permeability of the mold.

6. Any irregularity of permeability is likely to result, if the deficiency exists at or near the face of the mold, in the production of a porous or unsound spot in the casting. A loosely rammed

patch at the face of a mold simply represents a local excess of interparticle atmosphere and if this loosely rammed patch is surrounded by well rammed sand of lower permeability, it is obvious that the atmosphere, which is enlarged by the thermal attack of the metal, cannot properly be evacuated through the sand and may, therefore, be, in part, injected into the casting. So far as permeability is concerned, the ideal condition for a mold is one in which the permeability progressively increases as the distance from the mold-metal interface increases.

7. The molding sand under discussion in this paper is composed of silica particles with an addition of bonding material. The silica particles do not contain water nor do they contain any matter which can produce a gas or vapor when subjected to the heat attack of the cast metal. Mold gases, therefore, are produced from the binding media, of which water is one.

8. Particular importance must attach to the material which is used to form the face of the mold and it should be well understood here that the face of the mold includes the face of the gates. Insufficient importance is attached by a number of foundrymen to the provision of proper material at the gates of a mold and, while deficiencies of the porosity type may not generally be identified with failure to provide proper material at the gates, it is safe to say that many of the defective castings which are discarded are deficient because the gating system is either of improper design or the gates are produced from material inferior to the facing which is used to form that part of the mold in contact with the pattern for the casting proper.

9. The most common defect of the porosity type appearing in castings produced by green sand or skin dried practice, is generally defined as "pin-holes." This defect was discussed in two papers by the author[1] [2] and the presumed method of formation of this type of defect, as expounded in those papers, is fairly generally accepted by steel foundrymen.

10. It seems safe to assume that this pinhole defect, and also the larger defects which appear at internal corners or angles, are definitely the result of immigrant mold gases. These injected gases or vapors are produced by the heating effect of the cast metal upon the bonding materials, (including the water as a necessary com-

[1] Batty, G., *"The Most Potent Variable,"* TRANSACTIONS A.F.A., v. 38, p. 309, 1930.

[2] Batty, G., *"The Inter-relationship of the Pinhole Trouble and the Low Ductility Problem,"* TRANSACTIONS A.F.A., 39, pp. 861, 1931.

ponent of these), and the inter-particle atmosphere of the sand. In some cases, the proportion of cast metal to sand is such, by reason of the design of the casting, that it is practically impossible to evacuate the enlarged gases from certain parts of the molds at sufficient speed. In such cases, the foundrymen has to resort to local chilling to expedite the formation of a solidified film of cast metal to prevent the injection of mold gases. The permeability of the mold is a definite distinction from the permeability of the sand or sands which are used to produce the molds and in this particular, it may be said that sufficient attention has not yet generally been accorded the backing sand and the flasks or boxes in which the molds are produced.

11. As this paper is devised to treat of American practice, no attempt will be made to discuss such basic molding media as Chamotte which is used in Europe, molders' composition ("compo") used in Great Britain, nor the cement-bonded molding material which is used in France, and is being experimented with in other countries.

12. The basic material of American molding sands is silica sand and the modern tendency appears to be to arrive at standardization in producing synthetic molding sands by the addition of binders to washed and graded silica sand.

13. In dry sand practice, naturally bonded sands are now used to a much greater extent than in green sand practice and many foundries adopt the procedure of "blending" sands by producing mixtures of naturally bonded sand with washed silica sand, or with crushed rock sand, or with graded gannister, together with certain bonding media.

14. When a foundry is able to locate a source of supply of naturally bonded sand which meets all of its requirements by very simple modifications to suit the various types of castings in production, it may be considered fortunate; but there does not appear to be available in this country naturally bonded sands of the excellent and versatile type which exists, for example, in Belgium.

15. The modern trend in steel molding practice appears to be along the lines of securing adequate properties in synthetic sands, which may be used either in the green state or in the skin dried state, to produce castings of increasingly heavy types. It is recognized, of course, that where a mold must have great strength to resist the pressure of a large volume of metal, dry sand practice must almost inevitably be followed and there appears obvi-

ously to be a limit beyond which green or skin-dried practice may not safely go.

16. The porosity in castings which has its origin in the molding materials must necessarily be traced back and its source or origin found in the bonding materials or in the failure of the molding material, or the mold as a whole, to present proper permeability characteristics.

17. So far as molds and cores are concerned, it appears justifiable to state that their effect, in promoting unsoundness of the porosity type in steel castings, is the result of the injection into the metal of mold gases. These mold gases must necessarily be evolved from the bonding media, or must result from the inability of the mold to evacuate the inter-particle air which is enlarged or expanded by the thermal attack of the metal. It must be remembered that water is a bonding medium or is essential to the proper functioning of the solids which are used as bonding media in most molding and core making mixtures.

18. A consideration of this simple statement might lead one to the conclusion that a high permeability figure is of major importance in the production of a molding medium for steel castings, but it may be said here that a permeability figure, of itself, is no absolute indication that a sand is suitable for the production of steel castings irrespective of other considerations which enter into the matter to modify or complicate the application of such sand as a molding medium.

19. Admittedly permeability is important, but a permeability figure in any foundry must be related to other potent factors, one of which is the maximum pouring temperature likely to be encountered in the practice of that particular foundry.

20. To prevent porosity defects, each foundry has its own particular set of governing factors to take into consideration and no prescription of sand composition or constitution, permeability, green strength or dry strength can be considered safe unless it has been tried and proved suitable for the combination of conditions which govern the operation of any particular foundry.

21. This is particularly the case where green or skin-dried practice is to be followed and the main facts to be considered are:

1. General temperature of metal as delivered to the molds.
2. Molding methods; as example, jolt or squeezer.
3. Flask equipment.

4. Arbitrary prescription as to the relation of pattern size to flask size.

The foregoing points must be kept in mind when selecting the molding materials because of their interrelated effect upon the casting.

22. If it is essential that the casting in general be produced with a fine surface, a fine grained sand is indicated as being essential as the base material. Even with well rounded grains in the basis material, a high permeability cannot be expected from a fine grained sand. Assuming regularity of grain shape, permeability is not a linear function of grain size because the bonding medium is applied, or should be applied, as a uniform film on the surface of the grains. Therefore, a fine grained sand will be subject to a greater proportionate decrease of permeability by adequate bonding than will a coarse grained sand. Against this, however, there is a considerable measure of compensation in the fact that the proportion of atmosphere is considerably less in a bonded fine grained sand than in a bonded coarse grained sand. This factor alone is of considerable importance in arriving at a suitable sand mixture.

23. The preparation of facing sand from all new materials is an operation which is tedious and somewhat expensive as compared with the preparation of facing material from reclaimed sand, but the production of the highest grade of steel castings, as related to freedom from porosity and to perfection of surface, may demand the use of new sand as a thin facing of molds and gates.

24. Such facing sand will, in green and skin-dried practice, consist of a fine-grained sand of rounded grain shape bonded with a strong mineral binder, or with a vegetable binder of the cereal type, or with a combination of both, plus an amount of water adequate to develop plasticity and to promote the proper distribution of the solid bonding material upon the individual grains of sand. Into the prescription of amounts and types of binder to be used must enter the factor of type of molding operation. For instance, it is recognized that a sand bonded entirely with bentonite becomes fragile on exposed corners or angles if subjected to any air drying such as exists when the molds have to stand open for any length of time; whereas a sand bonded either entirely with cereal binder and water or with a mixture of cereal binder, bentonite and water does not exhibit surface fragility.

25. Snap molds, which are immediately closed after making,

may safely be faced with a sand bonded only with bentonite and will produce excellent castings; but for general and varied production of green sand castings, the author has found it advisable to use a mixture of bentonite and cereal binder to produce a composition which gives the best general or average results.

26. The gaseous product of bentonite is limited by the amount of water with which it is associated at or near the face of the mold at the time of pouring, but cereal binder has a gaseous product in addition to that of the water, with which it is associated as a bonding medium. Therefore, it appears more important to have a greater mold permeability—as distinct from facing permeability—when a cereal binder is used, whether alone or in combination with bentonite, than when bentonite alone is the solid bonding medium.

27. Fire clay, as the bonding medium, has not been found as safe and efficient in green-sand practice when prducing castings of fine superficial appearance as the bentonite-cereal combination of binders. This is probably due to the fact that reclaiming of sand and the use of reclaimed sand as a component of facing mixtures has become much more general in recent years than was the case formerly. If new facing material is consistently to be used, a good grade of fireclay as the bonding medium will produce excellent results, but in such a system of operation, proper care must be exercised in the production of the backing sand in order that such backing sand has a permeability equal to or greater than that of the facing material.

28. There is a wide divergence of opinion as to the permeability and moisture content of molding sand which may safely be used in green sand practice, but this divergence of opinion as to what is most suitable is related to the types of castings produced in different foundries and the quality of superficial appearance set as a standard by the different foundries. It is also related to the factors listed in a previous paragraph as being guiding or governing considerations in the selection of the molding material.

29. In skin dried practice, it is customary to select a grain size or a combination of grain sizes in the basis silica sand somewhat finer than is used in straight green sand practice, and to include in the facing mixture some small portion of liquid vegetable matter such as molasses or sulphite liquor. Of the two, sulphite liquor is preferred by the author, who believes that in certain circumstances the fermentation products of molasses impair the strength of the sand when heaps of wet sand have been allowed

to stand for some time and are then used as a component of the backing material.

30. In the skin drying operation, some of the water is evolved from the surface of the mold but some of it is driven back into the mold and forms a belt or film, approximately parallel to the mold faces, in which an excess amount of moisture is present. Unless the skin drying operation is properly and thoroughly carried out and unless the castings are poured within a relatively short time of the completion of the skin drying operation, the castings may be of a quality inferior to those produced in straight green sand practice.

31. Normally, skin drying is applied in the production of castings of somewhat heavier section than are regularly produced in green sand practice, and the general procedure is to use metal of lower temperature as the general section thickness of the castings increases. Hence, the thermal attack of the metal upon skin dried molds is less immediate and less violent than pertains in general green sand practice. In skin-dried practice, it is particularly important that the permeability of the backing sand be higher than that of the facing sand to produce immunity from blows, scale and pinhole penetration.

32. In dry sand practice, facing material of a still lower permeability may safely be used, and fire clay is generally the solid bonding material employed. Not much sand reclaiming is followed in dry sand practice but could with advantage be undertaken with a view to ensuring that the permeability of the backing material be in excess of that of the facing material.

33. When metal is poured into a dry sand mold, the primary thermal effect of the metal is to drive off the water associated with the fireclay. This water is converted into vapor and tends to move back from the mold-metal interface until it meets sand cold enough to condense it. It is fairly well known that if a dry sand casting is shaken out as soon as possible after pouring and the sand cleared away from it as much as possible a belt of sand is exposed, near to and parallel with the faces of the casting, that is distinctly wet.

34. If the permeability of the backing sand in dried molds is inadequate, the continued heating of the mold, as temperature is transferred from metal to mold, may result in the reconversion of the condensate into steam and the injection of such steam or water vapor through the solidified envelope of the casting, thereby producing a blow.

35. The location of the deposition of the initial condensate film appears to be related to the permeability of the backing sand and it is the practice of competent steel foundrymen to augment locally the capacity of dry sand molds by carrying vents from such mold locations as are likely to be subjected to extravagant thermal attack by the cast metal.

36. Turning now to the proposition of using reclaimed sand as a facing material, it may be said that excellent results are being produced without the use of any new sand as an addition to the reclaimed material, but it is also safe to say that the very highest degree of superficial appearance may not be attainable when using reclaimed sand as facing. This, in part, is due to the fact that reclaiming, as practiced, does not entirely eliminate all the deleterious products of the first or subsequent using of the sand.

37. Once sand has been used in the production of steel castings, it may become contaminated with small particles of wood or charcoal from flask bars and "soldiers", with minute globules of metal—fine splashings produced in the pouring operation—and is certainly contaminated with oxide of iron that adheres to the semi-vitrified face of the mold, as evidenced by Dierker.[3]

38. A good sand reclaiming system is to be found in a combination of screening and the pneumatic extraction of fine particles. However, it is essential that the semi-vitrified mold-face material be broken down completely so that the finely pulverized oxide of iron and the disintegrated silica be largely or entirely eliminated from the material which will be used again as a molding medium. To eliminate small pieces of wood or charcoal, it is essential that the sand be dried to some considerable extent before the reclaiming operation is undertaken in order that these lighter elements may be extracted pneumatically. The removal of small particles of steel, along with nails and gaggers, is achieved by a combination of magnetic separation and screening.

39. Provided the flow of the sand is not too rapid over the magnetic separator and the screen, the metallic particles may be substantially extracted, but, unless the sand is fairly well dried, small particles of charcoal and wood may persist in the material through the operation of reclaiming and become components of the facing mixture. Such contamination is not detrimental to the sand as used for backing material but is definitely detrimental if the sand is used as facing material.

[3] Dierker, A. H., *"Reclaiming Steel Foundry Sand"*, A.I.M.E., Technical Publication 261.

40. Particles of charcoal or wood will absorb a considerable amount of water and thereby become local spots of exceedingly high moisture content and may promote blows or pinholes in the casting. The same comment applies to particles of coke which may have been used in the interior of cores. Therefore, it is considered essential that substantial drying of the sand be a regular detail of reclaiming procedure.

41. Reclaiming of sand, for both green and skin dried production, is definitely of value, but the production of the highest grade of castings should preferably be associated with the use of a thin film of all new materials at the face of the whole mold, or at the gates, near the gates, and at internal angles produced on the casting by the mold.

42. When expensive bonding materials, such as bentonite and cereal binder, are consistently employed, the reclaiming system presents a very considerable economy and results in an adequate system of preparing both facing and backing sand from the same storage hopper of reclaimed material. For general practice in the production of light steel castings, it is necessary to add only about two-thirds of one percent bentonite and one-third of one percent cereal binder to reclaimed sand to produce a facing material suitable for application on about 90 percent of the mold surface exposed to contact with cast metal. This, as compared with three percent bentonite and one-and-one-half percent cereal binder required as an addition to washed silica sand to produce new facing material, is a distinct economy.

43. It also must be remembered that in the preparation of facing from all new materials, prolonged milling is essential to ensure the proper and uniform distribution of the plastic bond upon the individual sand grains. The reclaimed sand carries a closely adherent film of unimpaired bond which roughens the grain surface and promotes the ready distribution of the small amounts of new bonding material added so that the milling time on reclaimed sand may safely be only one-quarter of that necessary when preparing molding material from all new materials.

44. It is understood, of course, that what is referred to as reclaimed sand originates as new washed silica sand plus 3 percent bentonite and 1.5 per cent cereal binder in the specific example under discussion, and that a variable proportion of unbonded sand is injected into the material for reclamation by the disintegration of oil sand cores such as are commonly used in the production of light

steel castings. It has been found in practice that sufficient bond adheres to the sand grains throughout the reclaiming operation, despite the injection of unbonded sand from cores, to permit of this reclaimed sand being used as backing material after a simple milling with 3.5 to 4.0 percent moisture without any addition of new binders.

45. This, as compared with the total of one percent, by volume, of added solid binders to the reclaimed sand used for facing, ensures that the backing sand is of higher permeability, though of lower strength, than the facing material. In this detail, sand reclaiming, when properly conducted, links economy to the highly satisfactory use of old sand as a component of facing sand.

46. Into the consideration of the system of reclaiming used sand must enter a knowledge of some of the physical characteristics of the original basis washed silica sand. Inevitably there is, in the milling operation, some breaking down of the grains or particles of the silica sand but sands of different origin may, while appearing alike in constitution, grain size, and grain shape, behave quite differently in service. Particularly is this the case if any considerable proportion of the individual grains are fissured, as these grains tend to split into two separate pieces in the milling operation.

47. If a rounded grain splits into two equal parts, each of the two pieces will remain on the same sieve that originally retained the original grain, and if this example is multiplied, there arises a condition in the sand where a normal amount of bond will be inadequate to cover the additional production of surface area. Also, the cracked grains have assumed angular characteristics and depreciate the flowing quality of the sand in ramming.

48. Therefore, it is essential that in operating a reclaiming system, some scrutiny be exercised on the grain shape of the returned sand to ensure that the general supply of new material—originally to be used in making oil sand cores—is consistently of a type substantially free from any acute tendency to cracking or splitting. Inevitably, there is some destruction of sand with each cycle of use, the semi-vitrified film contaminated with iron oxide being rejected, after being broken down, in the reclaiming operation.

49. Even with the use of concentrated bond of the bentonite and cereal types, there is a gradual accumulation of bond material upon the individual grains of sand. Upon the addition of water, this residual bond film becomes mobile and is competent to transfer, in part, from the grains upon which it is residual to the un-

coated grains which are introduced by disintegrated oil sand cores, into the mass for reclaiming. A balance of constituents may need adjustment from time to time by the addition of either small amounts of new washed silica sand or of binder to compensate the variations incidental to production.

50. In some cases, it is practicable to use some of the coarser elements of the extracted fines, made available when the separation of fines is a two-stage operation, as a means of introducing comparatively heavily bonded fine silica particles as a bond diluent or distributor. Such an addition is also used to regulate the permeability value when an abnormal amount of unbonded sand is introduced in the form of cores. This is necessary if oil sand cores are made from a mixture of fine and coarse sand, the finer sand being used as facing material in making the larger cores.

51. Table 1 quotes a few examples from standard practice in controlling the properties of reclaimed sand. In each case the unwashed sample is dry material from the storage hopper, subjected to ordinary grain size analysis.

52. The comparative washed sample is the same dried sample—with the exception of the extracted metallic matter—subjected to prolonged agitation in 10 percent sodium hydrate solution. The sodium hydrate detaches the bond material and is decanted. Thereafter the residual sand is repeatedly washed with clear water and weak acid solution and is then dried. After drying, the sample is again subjected to grain size analysis, the total of bond and silt being reported as the difference between the total of the sand remaining for grain size analysis and the original weight of the sample before washing.

## SAND SPONGINESS

53. One occasional form of porosity has, through lack of a better definition, been described as "sand sponginess". This type of unsoundness takes the form of subcutaneous blow holes which are consistently spherical or well rounded in shape and exhibit an unoxidized surface. Such defects are usually revealed by machining and have, upon occasion, resulted in aspersions being cast upon the steel maker. In many of these small blow holes, it is possible to see a small particle of white or faintly yellowish matter which has a high silica content and it has been assumed that this particular defect was resultant upon the entrapping of individual sand grains below the surface of the metal in the casting.

54. The shape of the blow holes indicates that whatever gas

has been released from solution in the steel was liberated at or near the solidification point of the metal. It is, of course, possible that this particular type of defect may be related to the dissociation of a nitrogen compound at about the solidification temperature of the steel but it appears significant that these spherical subcutaneous

**Table 1**

COMPARISON BETWEEN WASHED AND UNWASHED SAMPLES OF PNEUMATICALLY RECLAIMED STEEL FOUNDRY SAND

| Grain Size | Sand A | | Sand B | | Sand C | |
|---|---|---|---|---|---|---|
| | Reclaimed | Washed | Reclaimed | Washed | Reclaimed | Washed |
| Per Cent On 20 Sieve.. | 1.5 | 0.8 | 1.0 | 0.9 | 2.0 | 1.9 |
| " " " 30 " .. | 25.4 | 14.0 | 17.0 | 9.8 | 18.9 | 10.0 |
| " " " 40 " .. | 27.6 | 18.3 | 26.7 | 12.7 | 25.8 | 16.7 |
| " " " 60 " .. | 40.4 | 50.0 | 48.0 | 52.0 | 48.8 | 53.0 |
| " " " 100 " .. | 4.1 | 7.9 | 5.7 | 10.8 | 4.0 | 7.0 |
| " " " pan ..... | 0.7 | 1.1 | 1.5 | 1.7 | 0.6 | 1.1 |
| " " Metallic .... | 0.51 | | 0.31 | | 0.5 | |
| " " Bond & Silt.. | | 8.0 | | 12.5 | | 9.8 |

blow holes of the particular type under discussion are very often found to contain the small particle of silica. The amount of silica in the cavity may be as little as, or less than, one-fiftieth the volume of the blow hole.

55. This form of defect may be promoted by any one of several causes but, as the gates of a mold have to sustain the maximum thermal and physical attacks of the cast metal, it is probable that failure of the gate material may be responsible largely for this particular type of porosity trouble. Anything which causes sand to be entangled with the metal may promote this form of porosity.

56. Procedure designed to prevent this type of trouble consists in the use of specially prepared gate cores for the heavier types of green sand castings. Distinct improvement has resulted from the use of gate cores instead of the orthodox molding of gates in green sand, and this particularly applies to castings which formerly were molded with green sand horn gates. It has been found a distinct economy to make up stocks of various types of gates as cores and to build these gate core assemblies into the green sand mold in the actual operation of ramming the mold by hand. Where machine molding operations are followed, prints are used to provide the spaces and the gate cores are located subsequent to the ramming operation.

57. A special preparation, which consists of ordinary washed

core sand plus an addition of silica flour competent to fill the interparticle spaces, is used for these gate cores. This results in a ma-material which is almost impermeable. It should be understood that this sand, loaded with silica flour, is not devised to be used in heavy or massive pieces, but that the gate cores should be designed of as light a section as permits of freedom from breakage in handling.

58. The sand and silica flour are milled together with not more than one percent of linseed oil. It has been found advantageous to make the linseed oil into an emulsion with steam in the proportions of one part oil to three parts water. With a total of 4 percent liquid in the mixture, the sand is fairly easy to manipulate. When the cores are withdrawn from the baking oven, they are lightly painted or lightly sprayed with coal tar on their service faces. It is important that an excess of tar be avoided.

59. The heat of the cores drives off the more volatile constituents of the tar and the resultant cores are, mechanically, very strong. They also resist to a remarkable degree the thermal and physical attacks of the cast metal.

60. In addition to the use of these tar-surfaced cores for gates, cores of a similar constitution may be used as inserts in the mold at locations likely to be subject to excessive heat attack by the metal. The part of the mold which is likely to suffer most is closely adjacent to the ingate and it has been found possible to reduce materially the incidence of porosity troubles by the use of insert cores in green sand molds in locations closely adjacent to the gates. Cores of this type are also particularly useful to provide tool-clearance recesses in large green sand castings.

61. There are other details of molding procedure which may contribute to "sand sponginess" as well as to other forms of porosity. Probably the most common of these is the misuse of gaggers. When, in the process of ramming a mold, a gagger is driven too close to the face of the pattern it almost inevitably results in the production of an excessively rammed film of sand between the gagger and the face of the pattern. This produces a locally impermeable area on the face of mold and results in the sand being either washed off or forced off the gagger by expanding gases as the mold is being filled.

62. Resultantly, there is produced an excrescence on the face of the casting, but the sand which has been detached may be carried forward in the mold and promote either sand sponginess, or a

so-called slag inclusion at the face of the casting. In some cases when the "slag" inclusion is removed by sand blasting a number of relatively deep gas holes will be found penetrating the casting. Particularly is this the case if the eroded sand is smeared as a thin film over a part of the face of the casting.

63. Heavy flask bars which come too close to the face of the mold may also promote defects similar to those produced by improperly located gaggers when hand ramming operations are employed. On the other hand heavy flask bars, when used in jolting or sand slinger production, sometimes result in soft spots or areas on the face of the mold. If the individual holder is aware of this particular liability to soft spots, or if it is apparent on the face of the mold when the pattern is removed, the molder will take extra sand and repair the defect with his trowel. In so doing, the molder will frequently produce locally over-rammed or locally impermeable places on the face of the mold wherefrom defects in the castings may subsequently be generated.

## SYSTEMS OF MOLDING

64. The various systems of mold production demand consideration when devising a sand for use in the steel foundry and the potential deficiencies of each system must be recognized as clearly as the founder recognizes the potential advantages of each system.

65. In dry sand practice, which presents the smallest liability to the various forms of porosity in the resultant castings, the sand is generally of an angular type, liberally bonded with fire clay and plentifully provided with water to ensure the mobility of the bonding material. A sand of this type, even though it does not flow well, presents no particular hazard if its liability to produce soft spots at the mold surface is recognized and equipment for ramming operations is so organized as to overcome the potential deficiency.

66. In green sand practice, which customarily employs a basis sand of a rounded grain shape, the flowing properties of the sand relate, in some degree, to the amount and nature of the bonds employed. It is essential, in this form of practice, to place some definite limit upon the maximum amount of water to be used and it therefore follows that the amount of solid bond must be controlled in relation to the water content to ensure that wasteful and potentially dangerous amounts of bond are not employed. The dilution of strong bonding media has already been mentioned but such dilution has some relation to the molding system which is employed.

67. In hand ramming, there is very little selective location of the finer constituents of a sand mixture and, in hand ramming, there is not the same potentiality for the automatic location of finer constituents at the mold face as exists in the jolt method of production.

68. Locally over-rammed spots are readily produced at the face of the mold in the hand ramming operation if the molder does not exercise proper care in the use of his rammer and these over-rammed spots may promote two different types of porosity.

69. The hand ramming system of operation does not automatically produce any pronounced gradation of permeability of mold as the distance from the mold-metal interface increases.

70. The production of molds from properly selected sand by jolt ramming, when limited to patterns of a suitable type, achieves a very desirable condition in the mold, in that the proportion of fine material at or near the mold face is greater than in the remainder of the mold. Particularly is this the case when the precaution has been observed of providing a backing sand of a more open type than the facing sand. But it must be remembered that this condition applies only to the faces of the mold which are horizontally disposed in the ramming operation.

71. Even with a sand of uniform grain size, the jolting system produces progressive permeability of the mold as the distance from the mold face increases, but the jolt system is definitely limited to castings of somewhat shallow design if all the system's advantages are to be maintained. Mold faces which are vertically disposed in the jolting operation do not become adequately rammed, and unless jolting is augmented by local hand ramming the castings may be distorted or sand may be detached from the loose vertically disposed faces by the metal and promote unsoundness of the porosity type.

72. The sand slinger resembles, in the types of molds it produces, the jolting system but has the advantage that in many cases the sand may so be directed into the mold as to produce satisfactory molds having deep vertically disposed faces. The slinger system does not produce the local concentration of finer constituents at the mold face to the same extent as does jolt ramming, but results in a mold having the desired progressive permeability, when suitable sand is used.

73. One defect of the slinger system which may be somewhat surprising to a number of foundrymen, has been instanced to the

author. It was noted that certain castings produced by the slinger method were afflicted with pinholes whereas other castings produced by the slinger method in the same period and from the current supply of sand were not so afflicted. The investigation of the cause of this trouble proceeded by a process of elimination and it was found that the defective castings were all produced from rigid metal patterns, whereas the satisfactory castings were produced from wooden patterns. The obvious inference here is that the irresilient metal patterns produced such an intensely hard face, with a consonant increase in the proportion, by volume, of water, in the slinger operation that the gases from the immediate mold face could not be evacuated at sufficient speed through the sand.

74. A simple remedy for this defect was found in sieving a thin film of sand upon the face of these metal patterns before commencing to sling in the bulk of the sand. This film of sand on the face of the pattern functioned as a cushion and prevented intense local over-ramming at the face of the mold.

75. The author is well aware that he treads on dangerous ground when he ventures to state that the squeezer system of mold production is the least safe and satisfactory of the methods in use in the steel foundry. The prime objection to the squeezer system is that it tends to produce progressive permeability in two directions in each part of the mold; namely, from the face of the part to the mid-line of the part and from the back of the part of the mid-line of the part. Actually, this is progressive permeability followed by decreasing permeability.

76. The squeezer system is applied generally in the production of small castings which demand the hottest of metal for their production and it has frequently occurred that castings afflicted with porosity were produced on the squeezer system from the same sand which produced perfectly satisfactory castings of identical type when hand ramming or jolting practice was followed.

77. Squeezing is generally employed on snap flask work and, in many cases, the snap molds are jacketed for pouring with an impermeable sheath on four sides. If the jacket and the base board are impermeable there can be little hope that the mold will present good permeability characteristics. She squeezer system is also deficient in that it does not produce adequately rammed vertically disposed faces.

78. What has been said of the vertically disposed faces in discussing the various mechanical methods of ramming a mold ap-

plies also, and in particular, to the vertically disposed downgate. At the risk of appearing unnecessarily repetitious, it is again stated, as the author's opinion, that the gate or gates of a mold are probably the most important part of the mold in relation to the prevention of some form of porosity trouble in steel castings.

## PIN HOLES

79. The type of porosity which has been described in steel castings as "pinholes" most frequently occurs at internal angles of castings produced by external angles of molds. It is a commonplace idea in steel foundry practice that the junction of two planes of a mold must be adequately radiused, but in escaping one set of liabilities, the founder renders himself susceptible to another set of liabilities. If too large a radius is imposed to effect the junction of two planes, such a radius may in some cases result in the production of such an enlargement of section as to promote internal unsoundness; hence, the size of a radius must have some fairly definite relation to the section of metal of the casting.

80. It is not proposed to recite at this time what has already been published in previous papers by the author and by others about the mechanism of the formation of pinholes, but it is essential at this time to repeat that pinholes are believed to be the result of immigrant mold gases. If such an assumption or belief is correct, it then necessarily follows that the liability to the injection of mold gases will increase as proportion of metal to sand increases.

81. A corner of a mold which is contacted on three faces by cast metal is more liable to inject gases into the cast metal than is the angle of a mold where metal is in contact with only two faces of sand. From the corners of a mold, the injected gases will produce a definite blow of substantial size unless either chilling or excessive radiusing is adopted, whereas along a radiused angle of a mold (internal angles and corners of castings being understood), the defects will consist of relatively small pinholes if the permeability is too low in relation to the temperature of the metal.

82. In its worst manifestation, the pinhole trouble can be seen in the castings after sand blasting but in some cases, probably the majority of cases, the defect may not become apparent until the surface of the casting has been removed by annealing and the elimination of annealing scale.

83. The pinhole defect is readily distinguishable from sand

sponginess by reason of the fact that sand sponginess porosity is exhibited as bright spherical subcutaneous cavities, while the pinhole defect takes the form of small elongated pear-shaped cavities which are almost invariably oxidized.

## PERMEABILITY OF THE MOLD

84. It is not sufficient that sand of adequate permeability characteristics be used in the making of steel castings but it is essential that the mold as a whole—which includes the flask or container—be of suitable permeability. The permeability characteristics of the sand are not the whole answer to the prevention of

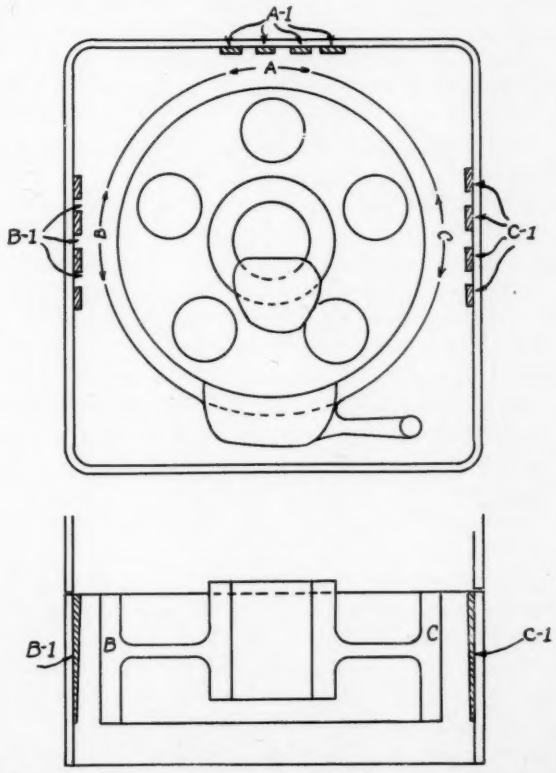


FIG. 1—GEAR BLANK CASTING SHOWING POROSITY AT A, B AND C. POROSITY WAS OVERCOME BY RAMMING TAPERED WOOD STRIPS AT POINTS *A*-1, *B*-1 AND *C*-1 TO ALLOW MOLD GASES TO ESCAPE.

pinhole porosity. Two examples out of a considerable number will be quoted to illustrate and amplify the foregoing assertion.

85. In these cases, the sand was contained in impermeable flasks with the result that the excellent permeability of the sand was negatived. Fig. 1 indicates a gear blank casting which, upon machining, showed three patches of porosity at the points *A*, *B* and *C* indicated on the figure. This casting was made on the partial reversal principle and the pattern was therefore not set central in the rectangular flask but was located approximately as shown in Fig. 1. Practically the whole of the casting was carried in the drag part of the mold and, by reason of the extravagant overheating of the relatively narrow belt of sand at points *A*-1, *B*-1, and *C*-1, but also by reason of the fact that proper venting was not ensured at these places, mold gases were generated at such a rate in excess of the venting properties of the mold at these locations that the casting was punctured by the immigrant mold gases and porous places were produced.

86. This example might be quoted as one illustrating a molder's failure to take proper safeguards, particularly so, in view of the fact that replace castings were made in the same flasks but with molded vents produced at the locations *A*-1, *B*-1, and *C*-1. These vents were produced by ramming up tapered strips of wood in close contact with the sides of the flask and withdrawing these after the pattern had been rapped. These replace castings were quite satisfactory and it is the author's opinion that, although the molder might be considered indictable in this matter, the real culprit was the maker of the flask. Unvented flasks represent a menace to any reliance the steel founder may be tempted to place upon the permeability figures returned on his molding sand, and it is gratifying to state with conviction that the flasks which are safest in this respect are those produced for the use of steel founders by steel founders.

87. A further example of the effect of practically sealing a permeable sand in a relatively impermeable container, is illustrated in Fig. 2. A number of these castings had been produced in snap flasks and were found pinholed on the bottom face. It will be noted from Fig. 2, that the metal section was unusually heavy for squeezer work and that only about 1½ in. of sand was interposed between the bottom face of the clutch casting and the bottom board. The slip jackets used on this mold were of the orthodox sheet metal type and, because of the weight of metal to be contained in the rel-

atively small mold, were made to cover almost the whole of the four inclined outer faces of the mold. The real trouble, however, lay in the fact that the bottom board was not permeable and by drilling a number of small holes through the bottom board to conform approximately with the circular base of the casting the trouble was entirely eliminated.

88. It is obviously impractical to use sand of proper or suitable permeability in flasks or other containers which materially impair the permeability of the sand but it must also be remembered that a well vented flask does not produce a mold mechanically as strong as an unvented flask. It follows that, with properly vented flasks, the founder must be prepared to be more generous in his allowance of flask space so that there may be interposed between ex-

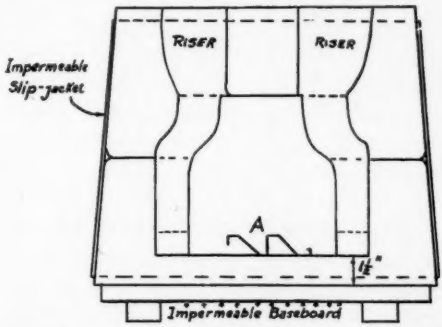


FIG. 2—DRILLING A NUMBER OF SMALL HOLES IN THE BOTTOMBOARD IN A PATTERN WHICH CONFORMED APPROXIMATELY TO THE CIRCULAR BASE OF THE CASTING, ELIMINATED POROSITY IN THE CASTING. CLUTCH FACE SERRATED AS INDICATED AT *A*.

terior faces of castings and interior faces of flask an amount of sand competent to produce the strength of mold essential to the production of undistorted castings.

## CORES

89. The precautions which have been taken in the production of molds to ensure the proper direction of evacuation of gases and vapors, must be amplified in the production of cores. As a generalization, it may be said that the proportion of thermal attack of cast metal is greater on cores than on molds, in that cores occupy an interior position in relation to the cast metal, whereas molds, in general, occupy an exterior position.

90. The composition of cores is varied to suit the various classes of castings and, where heavy cast structures are produced, the cores are made mechanically strong by bar or arbor re-inforcement in a strongly clay-bonded sand mixture.

91. In lighter cast structures or in structures of such design as makes it essential to avoid opposing any serious resistance to the solid contraction of the cast metal, it is necessary to use either oil sand cores or to relieve more strongly bonded cores to weaken the core structure.

92. Oil sand cores are deficient in that they will not withstand the prolonged thermal and physical attacks of cast metal incidental to the production of large castings and, while this deficiency may to some extent be repaired by the inclusion of a proportion of cereal binder in the core sand mixture, such an expedient is not strongly to be advised because the cereal binders have a voluminous gaseous product which is prejudicial to the proper evacuation of core gases.

93. In the production of cores, it is very essential to ensure that any rods or irons do not approach too closely the surface of the core. There is, with core irons, a liability to trouble of a type similar to that which may be produced by gaggers in molds. In clay bonded cores, the metallic reinforcement of the core expands during the drying and baking operation while the body of sand tends to contract. These opposed forces promote cracking of clay bonded cores and necessitate the filling of the cracks or fissures after the core is baked.

94. Unless the repaired core is thoroughly redried after the moist repair material has been put into the cracks, there is serious liability of promoting porous places in the casting at the point of contact of metal with the repaired part of the core. It is definitely an advantage to have all core irons ground or forged to a point at each end. This procedure minimizes the tendency of clay-bonded cores to crack in the drying operation. In oil sand cores, there is not the same liability to cracking in the drying operation.

95. Pulverized silica or mullite is used as the basis material for producing a surface wash to be applied to cores and to either of these two materials a proportion of bentonite is sometimes added to maintain the solids in a more permanent state of suspension than is possible without the bentonite addition. In some cases, a small amount of an alkali is added, in addition to the bentonite,

but this practice is not strongly to be recommended unless the amount of alkali is maintained at a very low figure.

96. Alternatively, molasses, sulphite liquor, or emulsified linseed oil are made constituents of the surface wash but these materials should be used sparingly as it is desirable to have in the facing mixture the minimum amount of material which will have a gaseous product. Any material, which is in solution in the water of the surface wash, is drawn into the body of the core while the solids are located on the face of the core to produce the desired smooth surface and, incidentally, to render the face of the core more impermeable.

97. The gas-producing constituents of the surface wash are, therefore, located in the sand immediately behind the face of the core and, unless the general permeability characteristics of the core are such as to allow the ready egress of gases, it is possible that the face of the core may be destroyed by the pressure of the gases generated, with sand injected into the casting to promote sand sponginess, and blows or pinholes produced at the region of core surface destruction.

98. Particularly does this apply in the surface wash of oil sand cores, and it has frequently been observed that the upper corners of oil sand cores promote blows where the lower corners of such cores have apparently promoted no blow. The lower part of the core has been subjected, in orthodox practice, to a more prolonged attack by the cast metal and it would therefore appear that, as the metal rises in the mold and subjects the core as a whole to a greater total heat attack, the core diminishes in its ability to conduct away through the vents the produced gases and the enlarged original atmosphere, so that the core is blowing at the upper surfaces when the level of metal reaches the top of the core.

99. In many cases, oil sand cores have been observed to promote a boil at the instant the metal flows over the top of them. A remedy for this condition is to be found in making the upper corners and upper surface of what is normally an oil sand core of a more impermeable clay bonded mixture. These composite cores are safer, particularly in the case where the core is of considerable vertical dimension in the pouring position.

100. In their effect upon the cast structure, cores resemble molds in that they may tend to produce porosity by reason of injected gases. These immigrant core gases are the product of the

associated moisture of clay, or are the gaseous product of cereal binder or oil, or are part of the original interparticle atmosphere of the core.

101. Jointing paste has been found to be a cause of porosity troubles originating with the core and it is advised that such paste be used as sparingly as possible and that cores be adequately redried—not necessarily rebaked—after being pasted together.

102. A dry core in a green sand mold has less capacity to absorb heat from the cast metal than has the mold. This statement is made with full acknowledgment of the fact that as the casting shrinks it may tend to produce between its surface and the mold a narrow space which functions as an insulator. On the other hand, the casting is contracting onto the core and maintaining close contact, but the cores which are made of an open structure—with the exception of the face,—cannot absorb heat as rapidly as can the exterior components of the mold.

103. As the size of a core decreases in relation to the volume of metal surrounding it, there is an increase in the liability of the core to promote blows or porosity in the cast structure. In part, this is due to the high rate of generation or enlargement of gas within the core structure, and in part it is due to the fact that the small proportion of heat absorption by the core so delays the thickening of the solidified film of cast metal around it that a relatively low gas pressure in the core structure may promote the injection of core gases through the weak thin film of solidified metal.

104. The tendency of oil sand cores to inject gases into cast metal may be appreciably minimized by using as the basis of the core sand mixture two distinct grades of sand, one grade being appreciably finer than the other. Such a mixture, however, manifests its advantages only if the cores are made on the jolting system, which will automatically promote the gravitation of the finer particles toward the horizontally disposed face of the core box. Alternatively two separate oil sand mixtures may be used, one consisting of the fine sand which is sparingly spread on the face of the box and backed by the coarser grade of oil-bonded sand.

105. The coal-tar surface treatment of cores devised to have an impermeable or almost impermeable face, has already been mentioned. Considerable work has been done with rubber bond as a general bond for cores or as a surface spray applied to cores of much more open texture than that of the sand devised to receive the coal tar treatment. In addition to rubber, other gums and res-

ins are being used as a surface spray or wash on cores for the production of light cast steel structures. When such materials are used, it appears essential that they be employed sparingly, as an excess tends to promote some of the troubles which the application of the material is devised to prevent.

## CONCLUSION

106. The diversity of types of steel castings makes it impossible to write a blanket prescription covering the composition and constitution of molding materials. Sand mixtures for both molds and cores must be devised from the large range of available materials to conform with the conditions imposed by the less mutable factors which tend to govern the system of production in any particular foundry. In stressing this point, the author maintains, however, that the founder should recognize the value of an orderly system of sand control, the functions of grain-size and grain-shape in promoting the desired mold or core characteristics, the varied values and deficiencies of different bonding materials, and, in particular, the advantages of producing molds and cores which exhibit the desirable condition of increasing permeability as the distance from the mold-metal interface increases.

107. This paper does not presume to cover the whole subject of porosity in steel castings but is limited to the types which are cutaneous or are very close to the skin or surface of the castings.

*(Discussion of this paper will be found beginning on page 394.)*

# The Mechanics of Porosity in Steel Castings

By R. C. Woodward,* Milwaukee, Wis.

**Abstract**

*This paper deals with that type of porosity which is seen just under the surface of castings, often called "pinhole" porosity. A study of rejection records of a certain steel foundry, over a period of 6 years, included 21,057 castings. By microscopic examination, a relation was found between the nonmetallic inclusions on the surface near the pinholes, and the amount of porosity. It was also found that porosity was greater in the summer. A theory which explained these facts is given.*

1. Porosity in steel castings is as old as the art itself and has inspired a volume of literature. The defective condition has been materially lessened by the use of aluminum in the metal and by sand control. In the remedial processes there have developed two opposing opinions as to cause and cure. Most metallurgists and melters unite in condemning the sand, while molding foremen and sand supervisors generally are convinced that the trouble lies mainly in the metal. The exponents of each theory are so strongly convinced that when the opposing opinions clash there is usually generated more heat than light; with the net result that improvement has been slow and that porosity has continued to be an expensive evil to the industry.

2. This paper deals with that type of porosity which is seen just under the surface of castings, often called "pin hole" porosity. While much has been written on the subject, comparatively little has been said as to just how any alleged cause produces the effect. It is attempted here to show the mechanics by which, under a set of conditions that often exists in steel foundries, porosity may be set up. It is felt that a more effective approach to the whole prob-

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Note: This paper was presented and discussed at a session on Porosity in Steel Castings held at the 1934 Convention of A.F.A. The discussion of this paper will be found beginning on page 394, where the discussion of the four papers presented at this meeting is reproduced.

lem will be possible if there is a clearer understanding of the manner in which generally recognized causes produce their effect.

3. In a certain steel foundry where porosity had been perhaps more persistent than is usually experienced, a study of rejection records was made covering a period of six years, 1927 to 1932 inclusive. A total of 21,057 castings rejected on account of porosity, was considered. It is sometimes assumed that porosity is an affliction of very small castings only. The average weight of these castings was 24.22 lbs., and of the total weight involved, 54.38 per cent had to do with pieces weighing 50 lbs. or more each. The melting units were acid open hearth furnaces, and the castings produced ranged in weight from less than a pound to 25 tons each.

## Rejected Catings Studied

4. It was generally believed that porosity occurred in cycles which seemed to be seasonal, rejections being heavier in summer than in winter. To determine how true this might be, tabulations were made by months and by quarters. Table 1 shows by months the total number of rejected porous castings, the ratio of porous rejections to total rejections, the ratio by weight of rejected porous castings weighing 50 lbs. or more each, and the average weight of all rejected porous castings.

5. Table 2 shows the same data as Table 1, as a summary by quarters. Fig. 1 is a graph of the ratio of porous rejections to total rejections. Fig. 2 is a graph of the total number of pieces rejected for porosity. Figs. 3 and 4 show the same data by quarters.

6. The year 1932 is not shown on Figs. 1 and 2 because of the low and erratic rate of production, the fact that at times the molds stood for exceptionally long periods before being poured, and because of radical changes in sand control. It was interesting and sometimes significant to note how persistently porosity would at times follow a single pattern, or the output of certain workmen, or the output of certain sections of the foundry.

7. While the records were being considered, the microscope showed that some specimens having excessive porosity had also excessive nonmetallic impurities in close proximity to the pin holes. By etching with various reagents, these nonmetallics were shown to be silicious, with some ferric iron, and probably with some alkalies and alkaline earths in small amounts. No ferrous iron was shown, indicating that they had no connection with the main body of slag.

**Table 1**

REJECTED POROUS CASTINGS BY MONTHS

| | Total No. Pieces | Percentage of Total Rejections | Percentage Weighing 50 lbs. or More Each | Average Weight |
|---|---|---|---|---|
| 1927 | | | | |
| January | 94 | 9.5 | 57.6 | 36 |
| February | 71 | 13.8 | 76.2 | 49 |
| March | 544 | 19.4 | 38.6 | 21 |
| April | 540 | 14.2 | 30.7 | 18 |
| May | 301 | 34.0 | 54.9 | 31 |
| June | 510 | 10.3 | 20.3 | 10 |
| July | 341 | 21.0 | 54.1 | 19 |
| August | 317 | 10.3 | 49.9 | 23 |
| September | 301 | 14.4 | 96.5 | 39 |
| October | 52 | 6.0 | 53.4 | 27 |
| November | 7 | .9 | 96.3 | 51 |
| December | 116 | 2.3 | 63.5 | 8 |
| TOTAL | 3200 | 12.8 | 50.2 | 22.2 |
| 1928 | | | | |
| January | 76 | .5 | .... | 3 |
| February | 91 | 13.3 | 55.0 | 30 |
| March | 19 | 3.9 | 86.2 | 89 |
| April | 159 | 6.7 | 59.8 | 18 |
| May | 604 | 14.6 | 65.5 | 19 |
| June | 696 | 34.7 | 76.5 | 35 |
| July | 583 | 19.0 | 81.8 | 36 |
| August | 709 | 7.6 | 53.0 | 15 |
| September | 782 | 6.1 | 34.7 | 10 |
| October | 833 | 15.3 | 60.5 | 22 |
| November | 357 | 9.4 | 46.4 | 25 |
| December | 181 | 8.8 | 29.7 | 24 |
| TOTAL | 5090 | 12.2 | 64.7 | 22.4 |
| 1929 | | | | |
| January | 4 | .8 | 88.2 | 142 |
| February | 64 | 1.0 | 6.6 | 17 |
| March | 348 | 5.9 | 16.4 | 8 |
| April | 435 | 18.7 | 42.6 | 2 |
| May | 1187 | 21.4 | 13.9 | 19 |
| June | 1945 | 34.7 | 38.4 | 22 |
| July | 774 | 20.2 | 60.6 | 23 |
| August | 417 | 15.4 | 23.7 | 17 |
| September | 302 | 18.2 | 63.3 | 29 |
| October | 163 | 15.1 | 80.2 | 56 |
| November | 35 | 3.4 | 72.0 | 30 |
| December | 219 | 5.4 | 35.3 | 18 |
| TOTAL | 5893 | 15.0 | 41.1 | 21.8 |
| 1930 | | | | |
| January | 620 | 15.6 | 46.3 | 22 |
| February | 1396 | 34.2 | 43.6 | 21 |
| March | 683 | 27.9 | 63.6 | 34 |
| April | 407 | 19.9 | 56.1 | 30 |
| May | 202 | 12.2 | 61.8 | 34 |
| June | 356 | 25.4 | 63.7 | 36 |

*(Continued on next page)*

**Table 1 (Continued)**

REJECTED POROUS CASTINGS BY MONTHS

| | Total No. Pieces | Percentage of Total Rejections | Percentage Weighing 50 lbs. or More Each | Average Weight |
|---|---|---|---|---|
| 1930 | | | | |
| July | 408 | 27.6 | 65.8 | 40 |
| August | 1241 | 31.6 | 50.8 | 19 |
| September | 454 | 43.1 | 81.7 | 46 |
| October | 49 | 11.1 | 70.8 | 54 |
| November | 145 | 25.8 | 69.6 | 48 |
| December | 53 | 1.0 | 12.4 | 8 |
| TOTAL | 6015 | 24.2 | 59.0 | 28.0 |
| 1931 | | | | |
| January | 31 | 3.9 | 33.0 | 12 |
| February | 67 | 27.4 | 65.2 | 38 |
| March | 456 | 20.4 | 61.4 | 37 |
| April | 192 | 40.7 | 42.2 | 37 |
| May | 113 | 13.6 | 70.4 | 43 |
| June | 14 | 9.0 | 86.9 | 45 |
| July | 4 | 1.6 | .... | 26 |
| August | 52 | 30.8 | 87.6 | 83 |
| September | .... | .... | .... | .. |
| October | 5 | 5.8 | .... | 22 |
| November | .... | .... | .... | .. |
| December | .... | .... | .... | .. |
| TOTAL | 634 | 11.2 | 62.4 | 40.7 |
| 1932 | | | | |
| January | 15 | 2.0 | .... | 2 |
| February | .... | .... | .... | .. |
| March | 52 | 10.9 | .... | 12 |
| April | .... | .... | .... | .. |
| May | 7 | 1.4 | .... | 12 |
| June | 143 | 47.5 | .... | 4 |
| July | .... | .4 | .... | .. |
| August | 1 | .... | .... | 10 |
| September | .... | .... | .... | .. |
| October | .... | .3 | .... | .. |
| November | 7 | 19.5 | 78.9 | 95 |
| December | .... | .... | .... | .. |
| TOTAL | 225 | 3.4 | 25.2 | 9.3 |
| GRAND TOTAL | 21057 | 15.7 | 54.4 | 24.2 |

8. Speculating as to what relation, if any, these inclusions might have to the offensive pin holes, it was assumed that excessive inclusions throughout a cross-section would probably mean excessive inclusions on the surface also; and special thought was given to the ones imbedded in the surface.

9. When molten metal enters the cavity of a green sand mold, considerable pressure is set up by the volatile mold sub-

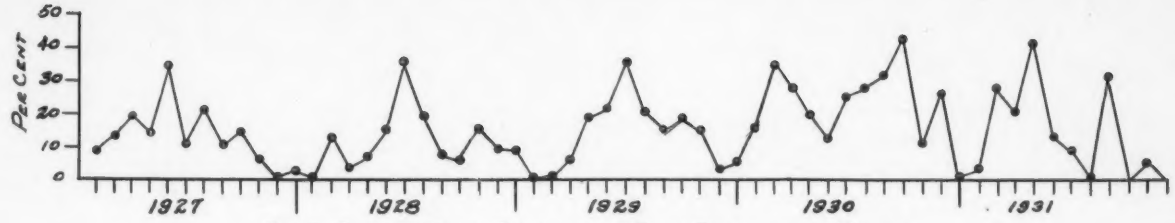



FIG. 1—RATIO OF POROUS REJECTIONS TO TOTAL REJECTIONS, BY MONTHS.

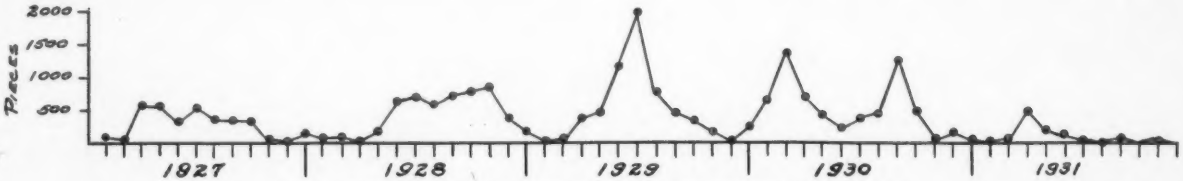



FIG. 2—TOTAL NUMBER OF PIECES REJECTED FOR POROSITY, BY MONTHS.

**Table 2**

REJECTED POROUS CASTINGS BY QUARTERS

| | Total No. Pieces | Percentage of Total Rejections | Percentage Weighing 50 lbs. or More Each | Average Weight |
|---|---|---|---|---|
| **1927** | | | | |
| 1st Quarter | 709 | 15.3 | 49.3 | 25.5 |
| 2nd Quarter | 1357 | 16.4 | 37.7 | 18.1 |
| 3rd Quarter | 959 | 13.9 | 61.4 | 27.2 |
| 4th Quarter | 175 | 2.6 | 62.6 | 15.9 |
| TOTAL | 3200 | 12.8 | 50.2 | 22.2 |
| **1928** | | | | |
| 1st Quarter | 186 | 4.3 | 63.8 | 25.0 |
| 2nd Quarter | 1459 | 20.4 | 72.1 | 26.7 |
| 3rd Quarter | 2074 | 10.4 | 65.1 | 18.9 |
| 4th Quarter | 1371 | 12.0 | 52.3 | 22.8 |
| TOTAL | 5090 | 12.2 | 64.7 | 22.4 |
| **1929** | | | | |
| 1st Quarter | 416 | 2.5 | 21.3 | 11.9 |
| 2nd Quarter | 3567 | 26.6 | 31.8 | 21.3 |
| 3rd Quarter | 1493 | 18.5 | 53.4 | 22.7 |
| 4th Quarter | 417 | 8.6 | 67.1 | 34.1 |
| TOTAL | 5893 | 15.0 | 41.1 | 21.8 |
| **1930** | | | | |
| 1st Quarter | 2699 | 25.9 | 51.6 | 24.2 |
| 2nd Quarter | 965 | 13.0 | 60.4 | 33.0 |
| 3rd Quarter | 2104 | 33.3 | 65.3 | 29.2 |
| 4th Quarter | 247 | 11.0 | 67.6 | 40.8 |
| TOTAL | 6015 | 24.2 | 59.0 | 28.0 |
| **1931** | | | | |
| 1st Quarter | 254 | 18.4 | 61.3 | 34.4 |
| 2nd Quarter | 319 | 20.9 | 55.5 | 39.0 |
| 3rd Quarter | 56 | 15.9 | 85.7 | 78.4 |
| 4th Quarter | 5 | 1.9 | .... | 22.0 |
| TOTAL | 634 | 11.2 | 62.4 | 40.7 |
| **1932** | | | | |
| 1st Quarter | 67 | 7.9 | .... | 9.6 |
| 2nd Quarter | 150 | 6.2 | .... | 5.0 |
| 3rd Quarter | 1 | .03 | .... | 10.0 |
| 4th Quarter | 7 | 6.1 | 76.6 | 97.9 |
| TOTAL | 225 | 3.4 | 25.2 | 9.3 |
| GRAND TOTAL | 21057 | 15.7 | 54.4 | 24.2 |

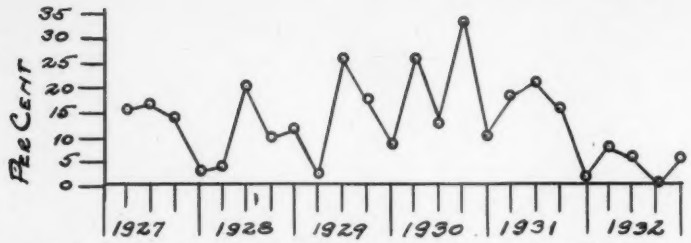



FIG. 3—RATIO OF POROUS REJECTIONS TO TOTAL REJECTIONS, BY QUARTERS.

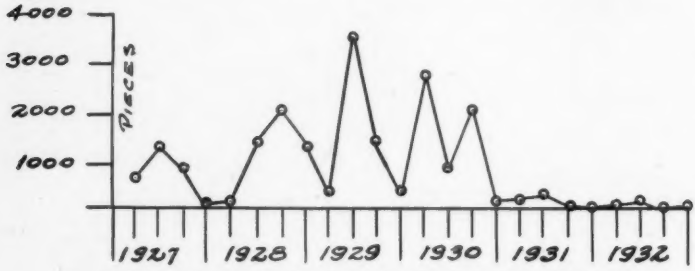



FIG. 4—TOTAL NUMBER OF REJECTIONS FOR POROSITY, BY QUARTERS.

stances, this pressure being equal in all directions. In the freezing cycle of a green sand casting a skin envelope is formed very quickly. Before the envelope is formed there probably is sufficient ferrostatic pressure to prevent the above mentioned gases entering the casting. As the envelope forms, the interior metal rapidly loses viscosity and ferrostatic pressure. The gas pressure continues to act against the envelope, which solidifies at approximately 2500 degrees Fahr. However, the surface inclusions, having a considerably lower freezing point than the envelope, continue to be liquid while they are subjected to this same pressure. The freezing point of the inclusions will vary with their composition, and could easily be 1000 degrees Fahr. less than their supporting steel envelope.

10. Therefore, there must come an instant in the freezing cycle of a casting when the envelope is solid, the surface inclusions liquid, with mold gases acting against the entire surface, and the interior ferrostatic pressure practically nil. With such a combination of circumstances existing, a minute amount of mold gas could enter the casting *through* the inclusion. It would meet

a much higher temperature and be forced to expand. Perhaps some of it would be ejected from the casting, but a cavity would be formed in the casting just under the skin where the metal would still be plastic, and the damage would be done.

11. It is generally said that porosity exists just under the skin of castings; and when some of this skin is removed by anneal-

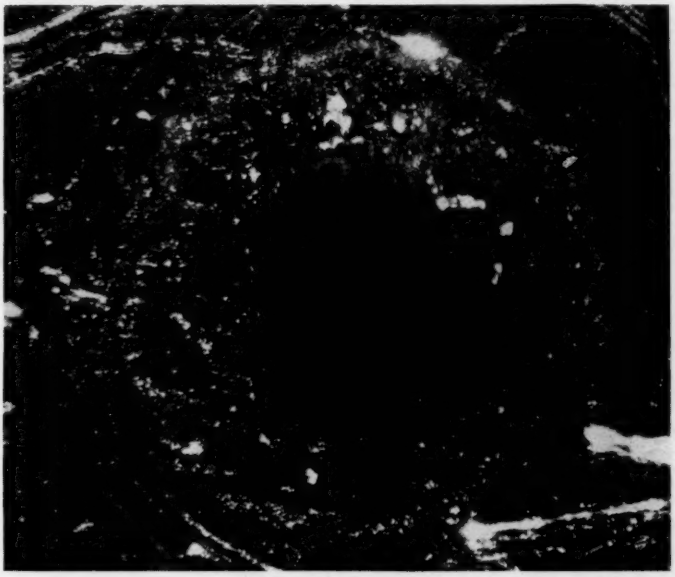
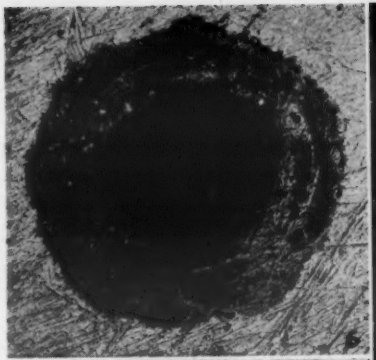
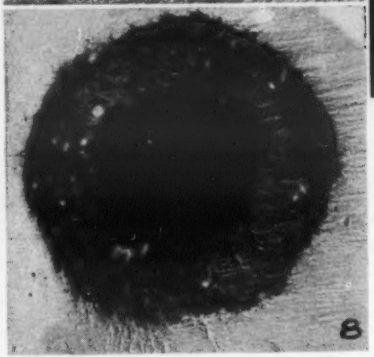


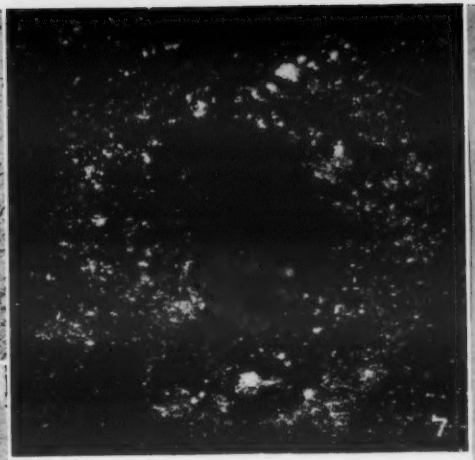
FIG. 5—PHOTOMICROGRAPH SHOWING RING OF SLAG IN NECK OF POROUS CAVITY. MAGNIFICATION 50X.

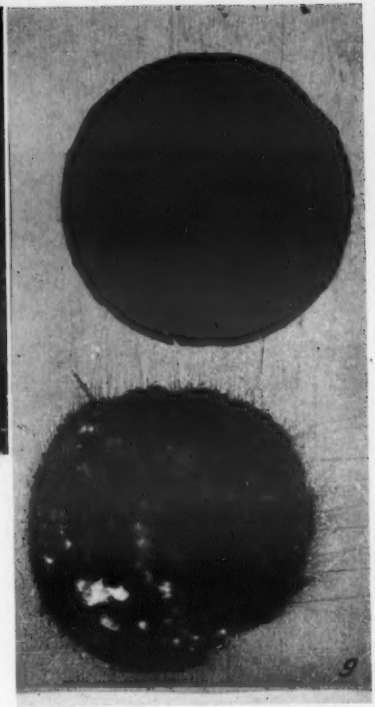
ing or machining, the hidden pin holes are exposed. If the theory advanced here is true, these cavities extend to the surface, but through inclusions which are themselves too small to be noted by unaided eyesight.

12. It was felt that if the theory had a basis of fact, sufficient searching should find pin holes with the nonmetallic matter in place, pierced by the hole through which the gas entered. They are not hard to find. Fairly large ones may be noted in visual examination, although the slag is very brittle. Sand blasting and other cleaning operations generally remove it. Fig. 5 shows a reproduction of a photomicrograph of a specimen taken at a magnification of 50x, showing the ring of slag in the neck of porous









FIGS. 6, 7 AND 8—PHOTOMICROGRAPHS SHOWING RINGS OF SLAG IN SAME LOCATION AS IN FIG. 5. MAGNIFICATION 50X. FIG. 9—PHOTOMICROGRAPH SHOWING RING OF SLAG AND LARGE MANGANESE SULPHIDE INCLUSION. MAGNIFICATION 50X.

cavity. Figs 6, 7 and 8 show other instances of the same phenomenon. Fig. 9 shows a similar slag formation, and close to it a large manganese sulphide inclusion not disturbed by mold gases.

13. Returning to consideration of the tabulated data, the assumption of seasonal porosity is in some degree substantiated. Possible factors which might cause it were sought; and by a process of elimination the materials used for binders were most suspected. If surface inclusions induced porosity, a concentration of slag

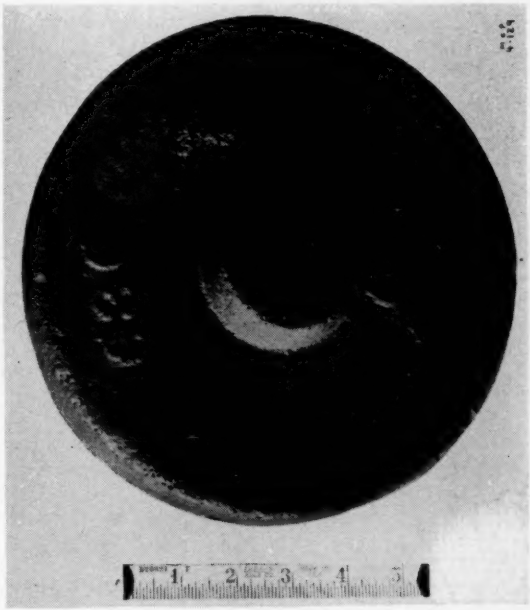


FIG. 10—POROUS CASTING MADE IN MOLD SPRAYED WITH ALKALI SOLUTION.

forming particles on the mold surfaces should show its effect on the casting. Two experimental molds were made from the same pattern, and one was liberally sprayed with a ten per cent solution of sodium hydrate. This mold, which was not dried after being sprayed, produced a very porous casting, and the other mold produced a sound one. This experiment was repeated a number of times, but while the expected porous result was generally yielded, it varied widely in degree. Figure 10 shows the picture of a porous casting made in a mold sprayed with the alkali solution.

14. Admittedly the opinion suggested here is just an individual one as to one cause of porosity. It may be wrong. It is advanced with the hope that it may be of some help to the industry at large in overcoming a defect in the product which is at times serious. It needs further investigation beyond the scope of the writer's limitations. If it stimulates such investigation and discussion, its presentation here will have been felt justified. If it points the way to any improvement in steel castings by emphasizing the need for both clean metal and clean sand, with properly regulated mold permeability, the paper will have served a useful purpose and contributed in a small way to the good of the cause.

*(Discussion of this paper will be found beginning on page 394.)*

# Function of the Steel Foundry Foreman in Preventing Porosity

By R. A. Bull,* Chicago, Ill.

**Abstract**

*The author, confining his discussion mainly to practical rather than to purely scientific phases of the pin hole problem, first devotes attention to conditions incidental to contaminating possibilities in metal transfer from furnace to mold. Then comments are made regarding the influence of aluminum in forming inclusions. Following this there are listed possible causes for porosity which are generally controllable to some extent by the men responsible for making molds and cores, and pouring the steel. Finally, comments are made regarding the inter-relationship of possible causes for porosity, and the delicate balance necessary to prevent this defect.*

1. In order to prevent being misunderstood, the author prefers at the beginning to define what he means by the term "porosity" as used in this paper. The word is here employed without attempting to draw a fine distinction between the several small cavities formed by gas, which may exist in steel castings. It is appreciated that there are interesting suggestive differences in the shapes, locations, and other observable conditions of those gas cavities that are relatively so small as to be excluded from conventional classification under the term "blow hole". Ordinarily those who make steel castings are accustomed roughly to designate gas cavities of large diameter as blow holes, and gas cavities of small diameter (generally less than 1/4 in.) as porosity or pin holes.

2. Some steel foundry metallurgists who have intensively studied porosity have narrowed their consideration to each of several distinctive kinds of gas cavities of small diameter, in the un-

* Consultant on Steel Castings.

Note: This paper was presented and discussed at a session on Porosity in Steel Castings held at the 1934 Convention of A.F.A. The discussion of this paper will be found beginning on page 394, where the discussion of the four papers presented at the meeting are reproduced.

derstandable desire to distinguish those that come from improper metal conditions, those produced by defective molds and/or cores, and some that can advantageously be more narrowly identified. The author is in full accord with the purpose behind these differentiating efforts when it is obvious that they are made with the intention of relating causes and effects. Occasionally some analytical studies of this character, while having much potential value, are confusing to the practically trained superintendent and foreman for whom these notes on porosity are specially written.

3. From what has been explained it will be clear that for the purpose of the present discussion porosity is regarded as any form of gas cavity of small diameter, whether the cavity is wholly or partially spherical or elongated, and whether the defect lies in the central portion of a member or at such a shallow depth as to be apparent after the casting is shaken out, or is uncovered when annealing scale is removed. Steel foundrymen know that, when porosity exists, frequently (but not always restrictively) it seems inclined to manifest itself in cavities that are very close to the skin of the metal. In these cases often the holes are elongated, having at some point diameters comparable to that of the ordinary pin. As is well known, some of these cavities, at the surface that is exposed on the removal of annealing scale, are only large enough to permit the careful insertion of a pin; hence, the customary term "pin hole".

## SIGNIFICANCE OF POROSITY PARTIALLY DEPENDENT ON TYPES OF CASTINGS

4. It is generally recognized in the steel casting industry that pin holes constitute one of the chief defects occasionally experienced by most foundries that specialize in the production of small, high grade steel castings. While the porosity evil is not confined to small pieces, its commercial significance in the lighter products of the steel foundry is greater than in the heavier castings, for several reasons.

5. In the first place, the standard of acceptable appearance is higher for small castings than for large ones. To considerable extent (although there are numerous exceptions to the rule), the approach to perfection in appearance desired by the average consumer becomes greater as the casting becomes smaller. This discriminatory factor is soundly based on economic principles, so far as these apply to the current viewpoints of industrialists. The average observer is not apt to notice and be critical about a few pin

holes in a base plate, but he would regard them as undesirable in an exposed motor truck bracket.

6. Another reason for the greater commercial significance of pin holes in light castings lies in the fact that, in many instances, the influence of a gas cavity is potentially more serious in respect to serviceability of the small part than in the case of the large casting. Of course this is due to cross sectional dimensions and the established factors of safety. A great many large steel castings are purposely made heavy, for the advantage that is derived partially from mass, supplementing dependence on the inherent stress resistance of the material. (Parenthetically it may be admitted, however, that in the past, probably a large amount of metal in castings was wasted in supplying weight unnecessarily. It seems worth while here to interject the comment that for numerous applications mass is very desirable, within reasonable limits; and that careful judgment should be exercised in reducing the weights of industrial parts to the apparent permissible minimum. Some present tendencies in weight reduction may be carrying a useful policy too far.)

7. It would be superfluous for the present purpose to elaborate on the difficulties caused for the foundryman by porosity. But it may not be out of place to mention the fact that, whereas gas cavities of every kind are much less frequently found now than they were formerly in castings of comparable kinds, the average consumer's attitude has increasingly become more exacting as to those details that affect surface appearance and more critical as to all factors that influence stress resistance. It would seem that the changes in preventative measures in the foundry and in the viewpoint of the customer substantially balance each other, with the result that porosity today is as serious a problem as it was 20 years ago, considered in respect to the current standard of acceptability adopted by the average buyer.

8. The author's comments on the causes and prevention of porosity in steel castings are prompted primarily by the hope that emphasis placed on certain manufacturing principles that are more or less generally known may be helpful to foremen who are expected to make steel castings free from pin holes. The paper is written mainly from the practical standpoint of regular production, not from the theoretical standpoint of scientific metallurgy. This comment might be misleading if the author did not now choose to testify gratefully to the considerable assistance received by practical men from competent technologists who have studied the

perplexing metallurgical conditions related to the subject. The author is attempting to supplement other contributions on the same topic by outlining in their apparently proper perspectives, some factors which can be readily understood by men on the foundry floor, and which may be major or minor causes for small gas cavities. If much of the present effort seems to some persons to be needlessly elementary, it might be suggested in justification for stating certain well known facts that the latter are so important as to merit repeated references. It is hoped that benefit may thus accrue to busy superintendents and foremen who frequently have their attention concentrated on production problems to the extent of causing occasional oversight of certain fundamentals.

## CONTAMINATION OF STEEL INCIDENTAL TO THE USE OF A LADLE

9. Everyone who is familiar with the circumstances knows that pin holes in steel castings are caused by gas which may come from each of several sources. We know that steel made as nearly perfect as is now commercially possible contains some gaseous and other impurities when it is discharged from the furnace. Experience demonstrates that well made steel as tapped does not contain enough gas to cause complaint regarding porosity, when all conditions of metal transfer from furnace to mold and when all conditions within the mold itself are as nearly perfect as they can be commercially maintained while making certain kinds of castings. We realize that gas of an amount and/or kind that may cause porosity in a satisfactory mold may exist in steel as it emerges from the furnace spout, if the metal is not properly conditioned before tapping. The fact that gas always is generated in every kind of sand mold, whether or not poured under ideal conditions of metal and mold, is patent to everyone who occasionally witnesses foundry operations.

10. Those who make steel castings require no evidence to demonstrate the fact that commercial steel that is satisfactorily (while not entirely) degasified before it is discharged from the furnace may absorb some gas that will be subsequently manifested by porosity, in one or more ways by which the metal may be contaminated in its transfer from furnace to mold, or in its function of filling the mold. It is a favorite indoor sport for some foundrymen to argue pro and con as to whether most of the porosity in steel castings is caused by defective metal or by improper mold conditions. It is doubtful whether many such general discussions

are very helpful, since they seem apt to make the furnacemen and the molding foreman blame each other dogmatically, during occasional porosity epidemics to which some steel foundries unfortunately are subject. The author believes, however, that the very nature of all the operations required for the manufacture of a steel casting are essentially such as to introduce a greater number of potential hazards in respect to molds than in respect to metal. There appear to be more details of the personal element involved in making most molds than in melting steel, with a correspondingly greater opportunity for shop practices to go wrong with the receptacle that will receive the metal to form a casting.

11. Turning attention to the first detail that concerns the foundry foreman, namely, the delivery of the metal from the furnace, it seems worth while to comment on the fact that the mere contact of the liquid steel with the atmosphere and with any material that may form gas may develop a condition in the metal ultimately manifested by porosity. The liquid metal generally seems to be highly susceptible to contamination through contact with gas and many other substances. Because the shop atmosphere presents the opportunity of an oxygen pick-up by the steel, metal that has minimum contact with the atmosphere from the time it is tapped until it is poured into a mold obviously has the least opportunity to become contaminated in its necessary transfer. Of course, this means that a bottom-pour ladle offers the least opportunity during transfer, for deterioration by means of oxygen (which we know to be one fruitful source of porosity). Logically then, the emptying of the furnace into a large bull-ladle, followed by transfer of the bull-ladle metal to the molds by means of shank pots carried a considerable distance mechanically or manually, provides the maximum opportunity, when transporting the metal, for it to absorb oxygen and thus acquire a greater tendency to throw the final balance on the wrong side, and cause porosity in the steel casting. This matter of balance will be referred to later.

12. The chief purpose of these comments regarding metal transfer is to emphasize the fact that the liquid steel always is in a receptive condition to the influence of every element which may be present as a constituent of the shop atmosphere, and of the linings for furnace spouts and for pouring ladles, even prior to entry of the metal into the pouring cup of the mold. At no time following the tapping of the heat does there exist an entire absence of conditions which may cause porosity, and which frequently result

in that defect if careful precautions are not taken by the men on the foundry floor. Obviously, this important fact should be kept in mind constantly by every member of the staff responsible for pouring, molding, or core-making details.

## INFLUENCE OF ALUMINUM IN PREVENTING POROSITY AND PRODUCING INCLUSIONS

13. Before discussing specifically those conditions obtaining within the molds which may cause porosity, a few comments on what many persons call final "deoxidation" seem to be in order, although it is the assigned function of another author to cover the subject of melting and conditioning the steel in such manner as to prevent porosity.

14. Much work has been done intelligently but unsuccessfully to find a substitute for aluminum which would have that element's marked affinity for gas, but would not injuriously influence the ductility of steel in the manner frequently demonstrated when aluminum is introduced and tension test bars subsequently are pulled. It is pertinent to remark that since it is *gas* and not merely oxygen which we want to eliminate, and since there are several gases present in the steel, the term "degasification" rather than "deoxidation" is the more appropriate one to use in connection with the final efforts to condition the steel for the prevention of porosity (and blow holes) in castings.

15. Some foundrymen pin their faith to special degasifying practices in the belief that these represent a technique which is superior to that involving the customary addition of aluminum. And there are persons who have held that essentially the incidental rather than the primarily sought effects of gas elimination by means of aluminum are different from the results obtained when another active degasifier is used. Some experiments made during the last few years have thrown considerable light on this entire question. Evidence has been presented by Sims and Lilliequist,* rather strongly indicating that we need not necessarily be handicapped by significant loss in ductility through the use of aluminum, but that we may introduce compounds that serve to make the impure products caused by aluminum addition to be much less injurious than they usually are, as ascertained by certain physical tests. Careful work that has been done suggestively points the way to

* Sims, C. E. and Lilliequist, G., *"Inclusions—Their Effect, Solubility and Control in Cast Steel"*, TRANSACTIONS, IRON AND STEEL DIV., A.I.M.E., vol. 100, (1932), p. 154.

feasible practices that may be depended on ordinarily for making inclusions behave themselves decently, when they are caused by adding aluminum to steel.

16. We know that when any element or compound eliminates any gas from steel, the constituents of the gas are not actually destroyed. They have merely become transformed into what will become solids, in some kind of association with other elements. These resulting nongaseous impurities become disseminated through the metal in the form of inclusions that usually are so small as to be observable only under the microscope. It seems unreasonable to the author to imagine that any degasifying element may be found which would not put into the steel substantially as large an amount of impurities in the form of inclusions as is created when we introduce aluminum—provided that the material substituted for aluminum would be equally effective in eliminating the gas.

17. If the facts are as suggested, several important matters must be kept in mind. Obviously it becomes highly desirable to try to develop a practice that may make harmless the inclusions created by degasification. The work done by the investigators previously mentioned indicates that iron oxide is very useful for the purpose referred to, by causing the inclusions developed by the introduction of aluminum to assume rounded rather than elongated shapes. Considerable evidence has been presented tending to show that it is the angular and elongated rather than the spherical inclusions found in aluminum-treated steel which are harmful to ductility, as indicated by the tension test. Seemingly, long inclusions have a tendency to form continuities, in chains somewhat roughly resembling irregular streaks of foreign matter. When the inclusions are more nearly spherical, they appear to maintain a sort of individual independence, having no significant inclination to closely approach each other.

18. It would be premature now to conclude definitely that we may cause inclusions in aluminum-treated steel, through the introduction of oxide or by other means, to assume forms with the result that the metal is not injured. Future tests of regular or special nature might show some injurious influence of inclusions resulting from degasification, however the inclusions may be shaped and associated. But until more information is obtained on this entire subject, it seems clear that the development of cleanliness standards for steel, as indicated by the number and/or total volume of inclusions per unit of measurement, should be approached very

cautiously by those who make or use steel castings. Parenthetically, it may be stated here that the subject now has practical rather than merely academic significance, because of the existence of some private specifications which prescribe standards of acceptability according to the microscopically observed amount of inclusions in specimens taken from steel castings.

19. Many foundrymen know that liquid steel, which always is potentially subject to contamination causing porosity (on account of the many chances for contact with gas and gas-forming materials) may be poured in certain portions of molds where design conditions are not conducive to the development of pin holes, while other members of the same castings or other castings poured from the same heat may be so designed as to be extremely susceptible to this troublesome defect. Experienced steel foundrymen know that with a given condition of metal and kind of green sand used for the mold, certain castings are not apt to show porosity, while other castings are so shaped as probably to develop pin holes, unless extra precautions against the formation of porosity are taken.

20. Now a test specimen might be chosen from a casting member of such nature as to exhibit no porosity, while showing a condition of cleanliness as observed under the microscope, satisfying the requirements of some highly technical specification. But at the same time many castings covered by the purchaser's order might be so designed as to require extreme precautions in preliminary and final degasification for preventing porosity. The observed standard of cleanliness in one microscopic specimen might actually indicate, because of a small amount of inclusions in it, an inferior condition of the metal considered from the standpoint of its susceptibility to such small gas cavities as are favored by design factors. In other words, the inclusion index for satisfactory steel castings may, dependent on the nature of the castings furnished, in reality be an indication of inferior final treatment of the steel intended for some specific foundry application, although the metal might be highly satisfactory for other purposes. Final degasification can be performed in such manner as to represent effective inoculation against porosity, in the face of serious hazards to solidity.

21. It is hoped that this digression on inclusions may seem to have its proper place in this discussion. Because there are and probably always will be held by some opposing views regarding such matters as inclusions in steel, frequently it is difficult to decide on the correctness of any opinion. Sometimes all persons con-

cerned are partially right and partially wrong. In any case, it ought to be clear to steel foundrymen making high quality material that dependence alone on any final, very effective degasifier may be a very unsafe practice. Of course this means that every feasible expedient should be employed for restricting to the smallest extent the formation of gas that may be taken up by the metal, and for providing adequate outlet for the gas that is produced.

22. Possibly some consumers would say that one obvious solution of this problem is to use among other expedients no mold materials that contain gas-forming constituents that can be discarded; and that therefore green sand should be prohibited for the manufacture of steel castings desired to be practically or entirely free from porosity. Undoubtedly many classes of steel castings should be poured in thoroughly dried molds. But the experienced steel foundryman required to make products of infinitely varied shapes, including many having designs of particularly susceptible nature in respect to shrinkage cracks, realizes that the substitution of baked sand for green sand for some steel castings ordinarily or occasionally would result in contraction defects more serious than those usually caused by pin holes. In any case, the present day steel founder, being required to consider carefully his production costs, must keep in mind constantly such willingness to pay as the customer may manifest. Every detail of manufacturing cost must be considered, including the item of dry sand molding, which of course usually is considerably greater than that of green sand molding.

23. However we may view this entire question, it is perfectly obvious to the steel foundryman who serves customers expecting freedom from porosity in their castings that there is commercial justification for establishing and maintaining many practices to restrict the formation of gas in the mold, following the conditioning and transfer of the metal in such ways as to bring it to the molds in the minimum state of gas contamination. It is the purpose of the author to itemize some procedures that are believed to be practical for attaining this objective. No originality for developing these practices is claimed in submitting the result of an effort to summarize precautions feasible to take on the foundry floor.

## Some Foundry Floor Conditions That May Cause Porosity

### (1) *Volatile Matter in Furnace Spout*

24. This condition may be caused by the use of molasses or

other liquid binders in the spout lining, or by insufficient drying of the spout lining.

25. It is the safest plan to make up the spout lining without any gas forming ingredient that can be feasibly eliminated. It is very advisable to dry the spout lining thoroughly, and to avoid any last-minute smoothing or patching with moist material, where part of the spout lining may have spalled or cracked while being dried.

(2) *Insufficient Dryness of Ladles*

26. This may be due to a generally poor shop system or to occasional carelessness. Every part of a ladle which comes into contact with the liquid steel should be made red hot if possible before the metal touches it. The practice of daubing a ladle lip with green molding sand or a clayey mixture is badly overdone in some foundries, and should always be avoided if possible. Moisture in plastic material is changed to steam when the steel flows over it, and some of this gas is very apt to be absorbed by the metal.

(3) *Volatile Matter in Ladle Lining*

27. The objectionable effect mentioned in item (2) can be produced by using for ladle linings certain dry materials that form considerable gas when in contact with the hot metal. Substances that are capable of forming gas under these conditions include all the farinaceous binders, which are not well adapted for ladle lining mixtures.

(4) *Lack of Steam Vents in Ladles*

28. Vent holes in ladles may be insufficient in number or be plugged with refuse material that should have been removed. Steam is generally created in a ladle lining when the vessel is filled with liquid steel and holds it for a considerable period of time. If the steam cannot escape through the lining and pass out through vent holes, it may be absorbed into the steel and cause porosity.

(5) *Old Sculls in Ladles Receiving Fresh Metal*

29. Frozen metal in the form of a ladle scull has an oxide formed on its surface as the result of contact with the atmosphere. This iron oxide may generate gas when molten steel is poured on top of the scull. If gas is developed in this way, it is apt to be taken up by the liquid steel.

(6) *Inadequate Final Degasification in the Ladle*

30. This may be due to disregard of instructions as to adding proper amounts of aluminum or other degasifiers. Such material is most effective in taking up the gas present in ladle-metal when the degasifier is put into the ladle immediately before it receives the steel, or when special methods are employed for plunging the degasifier into the filled ladle in such manner as to secure good distribution. (Regulated additions of any material to a teapot ladle are extremely difficult to make effectively.)

(7) *Exposure of Tapped Metal to the Atmosphere*

31. After the steel is removed from the furnace, contact with the atmosphere permits the absorption of oxygen by the steel from the atmosphere. This can result in appreciable degree from a very long carry of shank pot metal. Obviously, a bottom-pour ladle emptying steel directly into molds results in minimum atmospheric contamination of the steel. The oftener the metal is transferred with its surface exposed to the air, the more opportunity there is for oxygen to combine with some elements in the steel and form oxides that may injure the metal by causing porosity and/or other defects.

(8) *Ladle Additions of Alloys for Changing Chemical Composition*

32. Whenever "carbon powder", ferrochromium, or other similar material is placed in a ladle for changing the chemical composition of the contained steel, gas is produced. If any such material is added to the large ladle at the furnace spout, the gaseous condition of the steel that goes into a mold is not apt to be so pronounced as when the same proportions and kinds of alloying materials are put into shank pots (which may be used in conjunction with bull-ladles) just before molds are poured. The time element is important in permitting the developed impurities to rise toward the surface of the metal. These compounds are partially or wholly nonmetallic and are lighter in weight than equivalent volumes of relatively pure steel. Extra precautions need to be taken to prevent pin holes in castings when making ladle additions for alloying purposes, especially in the use of hand ladles.

(9) *Dipping Tools in Pot Metal*

33. Often a skimming rod which has been used for some time is dipped into a shank pot of steel, and when made red hot at the

end is pointed at the gate-cup to help the steel pourers clearly to see the opening for the metal stream. Occasionally, these skimming tools have adhering to them considerable oxidation scale and foundry floor refuse. Such a condition may result in the formation of gas taken up by the metal, causing pin holes. Considering the various kinds of gas-forming materials that may temporarily or permanently be attached to a skimming rod and be volatile at the temperature of liquid steel, the safest plan is to use only such skimming tools as are relatively clean.

(10) *Inadequate Feeding*

34. Some persons think this is a contributing cause for porosity, but probably the relationship is nonexistent, and is assumed after inaccurate diagnosis. Where the design of the casting and the nature and position of the risers are such as to prevent complete feeding at fillets and corners, occasionally there is found what seems to be a concentration of pin holes. In this way pin holes may *appear* to be caused by inadequate provision for shrinkage.

(11) *Excess Moisture in Facing or Backing Sand*

35. Very thorough sand mixing is necessary to prevent too much moisture in part of the batch, and not enough in another part. Skillful introduction of binders helps to distribute the moisture. When considerable dry binder is dropped into a mixer-batch at one time and immediately comes into contact with much moisture, the binder may become soaked and retain the water; possibly later forming a strongly bonded, lumpy mass of material that cannot be distributed properly through the sand, and may be much wetter than it should be.

36. The extent to which moisture is needed in the mixture as delivered from the sand mill, is largely regulated by precautions taken against the evaporation of moisture in the transfer of the sand to the molders, and in the storage of the sand at molding floors and benches. Weather conditions have considerable effect on the rapidity of moisture evaporation. During rainy days evaporation is greatly retarded.

37. The use of pure bentonite or a bentonite product calls for a smaller amount of water in the sand mixture than when fire clay as the sole or chief dry binder is employed. When water in the mixture as dumped from the mill does not get opportunity to evaporate to any extent, it may be best, from the standpoint alone of porosity prevention, to use a bentonite material instead of fire

clay as the principal binder. But other conditions, such as evaporation, should be kept in mind. If so much water evaporates as to leave the sand crumbly, of course trouble results in dirt spots and other defects. Probably the use of any cereal binder helps to prevent moisture evaporation, but care should be exercised in using such material because of conditions to be mentioned later.

(12) *Excess Dry Volatile Matter in Facing or Backing Sand*

38. It has been indicated that precautions should be taken when using cereal or farinaceous binders. They burn quickly when exposed to the liquid steel. One result of such combustion is the formation of gas. If ample opportunity is not afforded for such gas to escape, pin holes are apt to result. Quantity of binders and volatile materials should be carefully regulated, and they should be thoroughly distributed to prevent a surplus of such ingredients in a portion of a batch of facing. If considerable, poorly-distributed, volatile material is rammed against a pattern, that part of the mold will form a large volume of gas as soon as contact with the metal is made.

(13) *Low Permeability of Facing and Backing Sand*

39. One cannot state in accurate, general terms how low a permeability value in facing or backing sand causes likelihood of porosity. Not only does the sand mixture itself influence susceptibility, but the thickness of the mass of sand above the mold cavity has considerable to do with the matter. A cope having a shallow layer of sand (facing and backing combined) naturally permits gases to escape between the particles of sand more quickly than a cope having a thick layer of the same kind of sand. It is the safest plan to learn from experience with a given sand, the permeability that is necessary for the deepest molds; also for molds which, because of the design of the casting and the nature of the risers and vents, present maximum susceptibility to porosity.

(14) *Inadequate Mechanical Vents of Molds*

40. No one can lay down satisfactory rules for the venting of molds except in general terms. The location of risers have much to do with this. We know that vertical vents are better than side vents in letting any gas escape quickly. We also know that it is not possible to provide too free an outlet for mold gases if we want to take every feasible means to prevent pin holes. It is much safer to use many vents than to take a chance on a small number.

(15) *Low Green Strength of Facing*

41. This causes cutting or erosion, which in turn gives greater surface contact of the liquid steel with the individual particles of the sand mixture. Some of these particles may be readily converted into gas when the metal completely surrounds them, as it will ordinarily when bonded grains are broken away from the face of the mold proper. We can appreciate from this, that, while a weak facing sand causes cutting, it may at the same time create pin holes where the casting surface is the roughest. This striking combination of cutting and porosity has been seen on many castings made during epidemics of pin holes.

(16) *Low Dry Strength of Facing*

42. Green facing seemingly should be capable of partially baking quickly as the result of contact with the liquid steel, so as to acquire or retain strength while becoming further heated in the pouring operation. If it has necessary strength, it will of course retain its rammed form, and cutting will not result. If it crumbles while being heated, some of the trouble mentioned in item 15 may be experienced.

(17) *Oxidized Metal Parts of Molds*

43. These may be chaplets, chill plates, chill coils, rods, nails, wires, and other ferrous metal parts which have become rusty. Oxide that is caused by rusting, when in contact with liquid steel, forms gas that may often result in pin holes. In some foundries, rusty metal parts are more often found in cores than in molds proper, due to the spraying of green cores in which horse nails or other metal parts are secured.

(18) *Moisture Condensation*

44. The total moisture content of an entire mold may be satisfactory, while at the same time there may be an excessive amount of moisture on parts of the surface of the mold proper or in that portion of the mold forming the gate or sprue. This is often brought about by condensation. The longer a green sand mold stands on the floor, the greater is the degree of condensation producible under ordinary shop conditions. This concentration of water on the inside surface of the mold should be carefully guarded against by as much opportunity as can be afforded for reasonable air drying; also by pouring molds as soon as possible after they are closed. When it is necessary to store closed molds for many

hours on the pouring floor, frequently it is advisable to lift off the copes and see that all portions are satisfactorily dry before the metal is poured.

45. Moisture condensation can be partially guarded against by using bent rather than flat sheets of metal or other material, which occasionally are employed as covers to prevent refuse from dropping into sprues and risers. A cover of this kind shaped so as to provide a liberal air space helps to prevent an early accumulation of drops of water on the under side of the cover above the down-gate. The presence of water here indicates that at least a part of the channel for the down-gate may be saturated. Such a condition invariably produces steam, which cannot help but be absorbed by the steel as it rushes into the mold proper. Pin holes customarily form under such conditions.

(19) *Poor Mixing of Properly Selected Ingredients of Sand Mixtures*

46. Suitable proportions of useful volatile matter, such as grain products of various kinds, may be carelessly distributed in the mixing operation, so that too much gas-forming material may be segregated. These lumps made up largely of bonding material may be rammed against a pattern in a location which is vitally dangerous from the standpoint of pin holes. Obviously the proper course is to see that every batch is properly milled according to a definite schedule, and that each batch is of the proper size to prevent overloading the mill. If the batch is too large for the mill capacity, the materials in it cannot be properly distributed in the time which is satisfactory for a batch of proper sizes.

(20) *Facing Containing Too Large a Proportion of Farinaceous Binders*

47. As has been pointed out, contact of the liquid steel with cereal binders produces gas, because such binders are readily combustible. If the green strength of the facing depends too greatly on such volatile materials and not sufficiently on clay and/or bentonite, a large amount of gas in the mold will naturally result, causing liability to pin holes.

(21) *Excess Volatile Matter in Cores*

48. Occasionally cores contain a large total amount of gas-forming materials, due to the use of farinaceous, liquid, or pitch

binders. Some cores are so shaped and/or placed in the mold that satisfactory outlet for the developed gases cannot be provided, if much gas-forming material is contained in the core mixture. This condition may result in an absorption of considerable gas by the steel and pin holes in the castings.

(22) *Dried Cores That Have Absorbed Moisture*

49. When practice justifies the use of a baked core, it should be thoroughly dried and then stored in a way to prevent its absorbing an appreciable amount of moisture. It is well known that the use of an oil binder is preferable to other binders from this standpoint, although there are other factors such as cost which must regulate the choice of the binder.

50. When desirable mold conditions call for a core that should be thoroughly dry, and the core has been carelessly stored in a place that caused it to take up moisture, the extra amount of gas subsequently generated may result in considerable porosity.

(23) *Inadequate or Improperly Placed Core Vents*

51. Probably the venting of cores cannot be overdone. In many cases, vents in cores are not as large as they might easily be made for maximum security against the entrapment of gas. Holes for such a purpose should be liberal in size, largely because small holes are so easily choked by accident (as when a small pebble may become lodged in the end of the vent hole). Every core contains some material that will produce gas when in contact with liquid steel. Metal flowing over a defective core forms gas which may not have a chance for complete escape, but may cause gas laden steel finally to lodge in a part of the mold that is not close to the troublesome core. In this way, gas picked up by the metal from a core or part of a mold proper may result in pin holes in another part of the casting, deceiving the investigator as to the disturbing location.

(24) *Impurities in Sand Batches*

52. Pin holes on one occasion were found to have been caused by particles of coal in the fire clay put into the facing sand. Fire clay deposits in the ground often immediately adjoin coal seams. When such clay is not skillfully mined and prepared for use, it may be mixed with coal fragments, which of course are volatile. Care should be taken to see that no material such as clay intended

to be pure contains ingredients that might form gas that could serve no desired purpose but might be a cause of porosity.

(25) *Susceptible Design of Castings*

53. Experienced steel foundrymen know that a casting may be of such design as to make it particularly susceptible to porosity. Often this seems to be due partly to a mold surface of large area compared with the weight of the casting. The greater number of square inches of green mold surfaces that are in contact with the liquid metal, obviously the more opportunity there is for the steel to absorb gas from the mold. Castings that are of such designs as to cause extreme liability to pin holes should be made with extra precautions for venting as well as for every other manufacturing detail that may produce or confine gas.

54. In the case of many castings that seem inclined to have pin holes, skillful design of the gating arrangement is helpful. A gate that tends to force the gas ahead of the metal in a continuous flow is preferable from a porosity as well as from other standpoints. In some shops, certain castings which originally gave much trouble from porosity have been freed from this difficulty merely by changes in the design of the gates.

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55. Before the author wrote his paper, he had the opportunity of reading the manuscripts prepared by his colleagues who have made contributions for this Symposium. This prompted the author to think that his cooperative effort might best be confined largely to a listing of some possible causes for porosity; and that this treatment might advantageously be restricted to such possible causes as are wholly or partially under the control of the foundryman whose responsibility begins with the delivery of the metal from the furnace spout. The effort has been made to avoid such comments as in substance might seem improperly to encroach on the fields covered by the other Symposium authors. With this explanation, it is hoped that the preceding analysis, listing some possible causes by name, and including brief comments on each suggested cause, will be clearly understood.

56. The classified list is not submitted in the belief that there has been mentioned every major or minor cause for pin holes that may be related to conditions incidental to molding, core-making, gating, venting, storing, pouring, etc. Furthermore, it is not main-

tained that every factor herein listed can be proved to be either a regular or an occasional cause for porosity. Where any detail of shop practice may be suspected as an occasional producer of pin holes in the steel casting, the foundryman may wisely adopt precautions to keep this possible factor under proper control, if for no other reason than because it is under suspicion.

57. The preceding list of possible causes was prepared without the effort to name these in the order of their relative importance or in the order of consecutive shop operations. Probably it will be clear to any student of porosity that the author has subjected himself to the risk of logical, negative argument, in so far as some possible causes have been indicated. On the other hand, there must be numerous causes for pin holes which have not even been suggested in the above listing. Long experience in fighting porosity makes the author believe that his attempted analysis probably has many deficiencies. Nevertheless, good may be accomplished if the naming of possible causes serves merely to emphasize for some foundrymen, whose duties have prevented them from intensively studying pin holes, the importance of exercising the utmost care in regulating many details of shop practice that may be related to this defect, which frequently is very baffling.

## INTERRELATIONSHIP OF FACTORS THAT FAVOR POROSITY

58. In the first part of this paper mention was made regarding a condition which may now be briefly touched on as a closing comment. Apparently there is a very delicate balance which needs to be maintained between the combination of conditions that will prevent porosity and the combination of conditions that will cause it. One detail of foundry practice, among a good many, may get out of hand sufficiently to disturb the balance and throw the weight on the wrong side of the scale, resulting in pin holes. It may often happen that, when porosity occurs in very troublesome degree in the steel foundry, there are several causes operating in unison. The author's experience causes him to think that this condition usually prevails in times of porosity trouble, in plants making small steel castings in green sand, while pin holes in large castings poured in dried molds probably arise more often from a single factor. Whatever may be the kind of steel casting under consideration, it is clear that more trouble for the producer is apt to result when several potential causes for gas cavities exist, as compared with a single cause. Thus, the inadequate venting of a large core

and the condensation of moisture over-night in a sprue might cause pin holes, whereas the defect might not be occasioned by either one of these conditions if it happened to prevail alone in the affected mold. In similar fashion, the combination of a poorly dried shank pot and an excessive amount of cereal binder or of moisture in green facing might throw the balance on the wrong side, while neither of these factors alone might have caused trouble. It would appear that every cause for pin holes, whether occasionally it can be positively identified as a primary factor or not, frequently may be a contributory one. The procedure logically suggested by this line of thought is unremitting skillful attention to every detail of foundry practice that is known or is thought to be controllable.

*(Discussion of this paper will be found beginning on the following page.)*

# Discussion — Symposium on Porosity in Steel Castings

*The papers presented at this Symposium on Porosity in Steel Castings, the discussion of which follows, are:*

*Preparation of Steel to Avoid Porosity in Castings, by C. E. Sims, American Steel Foundries, East Chicago, Ind., pages 323 to 338 inclusive.*

*The Relation of Molds and Cores to Porosity in Steel Castings, by George Batty, Crucible Steel Castings Co., Lansdowne, Pa., pages 339 to 363 inclusive.*

*The Mechanics of Porosity in Steel Castings, by R. C. Woodward, Geo. H. Smith Steel Castings Co., Milwaukee, Wis., pages 364 to 374 inclusive.*

*Function of the Steel Foundry Foreman in Preventing Porosity, by R. A. Bull, Consultant on Steel Castings, Chicago, pages 375 to 393 inclusive.*

GEORGE BATTY[1]: This is indeed a very interesting paper which Mr. Sims has presented. It is particularly interesting to me because, in 1923, when I presented to the Sheffield Society of Metallurgists and Metallurgical Chemists the proposition that steel could be over-reduced in the electric furnace, and advocated the reversion of the steel to a proper condition by a late addition of iron oxide, one of our most prominent metallurgists stated that it was appalling that any man should go there and tell them to put oxygen back into the steel when all their energies were bent on eliminating it. Mr. Sims now insists, in a distinctly scientific paper, that what certain practical men have persisted in doing is correct. He states that it is desirable to have in the electric furnace a long and vigorous boil and, further, that it is undesirable to maintain the metal in the furnace for any protracted period in the fully reduced or deoxidized condition. A number of us have known this, have insisted upon it, and have practiced it for many years and I personally have advocated, in the making of acid electric steel for castings, boiling the heat down to as low as 0.12 or 0.13 percent carbon. This practice ensures such an excess of FeO in the steel as to promote the almost entire elimination of initial oxidation products.

In the production of acid electric steel, it is definitely advisable to avoid strongly reducing conditions in the furnace until the bath has attained a temperature which is known to be adequate for the work which is to be cast. If, by any combination of circumstances, the over-reduced condition manifests itself in samples which are taken from the furnace, it is definitely desirable to adjust the condition of the metal and the slag by a late addition of iron oxide. I have even gone so far as to make this corrective addition of iron oxide in the ladle during tapping.

In the making of light steel castings in green sand molds, metal of a definitely high temperature must be used and, because of the effect of

[1] Crucible Steel Castings Co., Lansdowne, Pa.

this high temperature upon the molding materials, a strong supplementary deoxidizer such as aluminum must be used. The method of adding this supplementary deoxidizer must be carefully controlled if we are to avoid serious impairment of some of the physical properties of the resultant castings and I can readily endorse Mr. Sims' statement that one type of porosity cannot be eradicated by an aluminum addition. This particular form of porosity I do not intend to discuss because I feel sure that Mr. Melmoth has some pretty definite information on the point and may be moved to tell us about it.

In closing, I would express the view that this paper by Mr. Sims demands a great deal of study and will promote a great deal of discussion of benefit to our industry.

R. A. BULL[2]: I should like to endorse Mr. Batty's tribute regarding the value of the paper and the need for a thorough study of the information given by Mr. Sims. Perhaps most of you know that Messrs. Sims and Lilliequist of the American Steel Foundries, made a very important contribution* some years ago to the American Institute of Mining and Metallurgical Engineers, which deals with a subject directly related to the one Mr. Sims discussed in the present paper. I recommend strongly that all of you get hold of that paper and read it carefully, if you have not had the opportunity of doing so previously.

In paragraph 57 of Mr. Sim's paper, there is one significant sentence which I commend for your own thoughtful consideration in trying to work out in your own minds some of these problems that are related to the topic: "Steel can be safely superheated to a considerable degree before deoxidation, but the same amount of superheating after deoxidation is apt to result in porosity." I think there is a lot in that.

JOHN HOWE HALL[3]: I noted the same point to which Major Bull called attention, that superheating after deoxidation is apt to result in porosity. I wondered how far that is true, that is, whether we must feel that a deoxidized heat must never have its temperature raised high enough to pour small castings. If that were one hundred per cent true, I am afraid that I would be constantly in trouble in our own shop as some of the steel we make is either deoxidized or pretty well deoxidized before we get it completely hot. I also am moved to wonder whether a heat which has melted low in carbon and given very little boil, is necessarily a gassy heat? I know that in Mr. Sims' own practice they make a great deal of steel with manganese around 1.50 per cent, and I would like to raise the question whether that steel is less apt to be gassy than steel of normal manganese, and also whether it is possible to melt those high manganese heats flat or nearly flat, low in carbon, and then bring them back without getting a gassy heat? My own experience is that you can do it without having trouble with porosity or gassiness. The paper reminds me forcibly of a remark I made yesterday, that it is wonderful how many things we knew the full answer to when we

[2] Consultant on Steel Castings, Chicago. Ill.

* *"Inclusions—Their Effect, Solubility and Control in Cast Steel,"* TRANS. A.I.M.E., 1932.

[3] Taylor-Wharton Iron and Steel Co., High Bridge, N. J.

were thirty, we don't know so much about today when we are a little older.

CHAIRMAN F. A. MELMOTH[4]: I believe in the boiling method of making acid electric steels, at any rate, and an acid electric furnace can be taken as constituting a very large part of the production of the lighter steel castings in this country. Perhaps this is rather in confirmation of several of the remarks made by the present author, but one point is raised in this paper which is not stressed and is not gone into very seriously. Mr. Sims mentioned the fact that silicon may act as, shall we say, an intensifier of the ability of the steel to dissolve nitrogen. Frankly, I do not know, but I do know this, that practical steel founders have a lot of things which they have noticed over a long period of years which these points tend to elucidate. I remember more than one man telling me that if they used too much shop scrap they ran into epidemics of porosity. Naturally I wondered why, because I have seen exactly the same thing.

It is not necessarily to be blamed on the use of shop scrap, but it is rather significantly removed by a change in the amount of shop scrap or the type of scrap being used. Then, on top of that comes the further point that that phenomenon appears to be more likely to occur if the steel is a high silicon material, which checks again with the remark made in this paper by Mr. Sims. It also is more liable to occur if chromium is existent in that returned scrap, which again rather tends to check the paper.

I have in mind some steel which contains an appreciable quantity of chromium and is high in silicon, and such steel will approximate this analysis: 0.20 per cent carbon, 2.25 per cent silicon, 3.5 per cent chromium, and I think everybody here who has made steel will say that that would be about the deadest stuff to put into a mold. I have seen that positively rise in the mold and no amount of aluminum had the slightest effect in quieting it. It seems that this rising in the mold must be due to an evolution of gas from some place or other, because the aluminum does not affect it, but a change in the scrap promptly did so.

MR. HALL: I can add something from my experience which I do not know the explanation of, but which may be useful to Mr. Sims and some of the others who are working on these problems. That is that a small bottom blown Bessemer converter always produces gassier steel than the side blown converter does.

I have seen a great deal of steel made in the bottom blown converter, rise in the molds, and have learned in the last fifteen years that the side blown converter is far less prone to produce gassy metal. I confess that I have never found out why that is so. In our bottom blown converter at High Bridge, up to the year 1909, we had found it impossible to produce 0.25 per cent carbon steel free from porosity. After that, we succeeded in doing so, but only by using 1.20 per cent manganese and about 0.50 per cent silicon. How much the change in composition assisted us, and how much the use of aluminum and calcium silicide

[4] Detroit Steel Casting Co., Detroit, Mich.

together accounted for our success, I do not know. All this is more or less irrevelant to the present day steel making practice, and yet there may be something in these experiences which bears on steel making practice in the electric furnace and the open hearth furnace.

MR. SIMS: It might be well to emphasize at this time that the recommendations made for the avoidance of gassy steel are more or less ideal. They are not always all practical or necessary. Although a long and vigorous boil is advocated, a very moderate boil often suffices as mentioned by Mr. Batty, or as Mr. Hall suggests a heat of steel can sometimes be melted flat without any boil and still not rise in the molds. Nevertheless, this last practice is dangerous and invites trouble. We never take that risk.

Mr. Batty favors going to a low carbon in the range of 0.12 to 0.13 per cent. Whether that is necessary or desirable may depend on other conditions. In electric furnace practice, a low carbon charge is used and in this case it may be necessary to go very low to get sufficient boil. On the other hand, if the charge melts down with a carbon in excess of 0.50 per cent, as in open hearth practice, it is unnecessary to go so low to get a good boil or sufficient oxidation. Likewise, many charges have been superheated after deoxidation without dire effects. Even so, it remains as an apparent fact that many "off" heats can count this practice as contributing largely to the trouble. The effect depends on such factors as temperature and time of superheating, and exposure of the metal to available gases.

In further reply to Mr. Hall, I will say that our custom calls for no change in practice when making medium manganese steel. However, we do go lower in carbon than we do for an unalloyed heat to finish with the same carbon content.

In regard to Mr. Melmoth's assertions as to the potency of high percentages of shop scrap in causing porosity in steel, I believe a logical explanation can be based on the premises of the present paper. A large proportion of shop scrap would usually mean a high silicon charge. The oxidation of silicon is strongly exothermic and heats the bath while providing no agitation. If the bath reaches a high enough temperature before the silicon is eliminated the remaining silicon will not be oxidized. A high residual silicon causes retention of gases which later result in porosity.

I will venture to explain Mr. Hall's problem of the bottom blown and side blown converters on a similar basis. The bottom blown converter has a tendency to run excessively hot while the side blown converter is somewhat more amenable to temperature control. Converter steel averages higher in nitrogen normally than does open hearth or electric steel. However, the higher temperature favors high residual silicon which in turn causes retention of gas in solution. The high temperature itself increases the solubility for gas.

MAJOR BULL: I do not know what definite basis Mr. Batty has for reaching his conclusion in his paper on the greater tendency to porosity of squeezer molds as compared with other molds. I think it would be very interesting if experiments could be made—possibly they have been

made—to show results on a given type of susceptible casting, in a given heat. We know there are certain shapes of castings what are susceptible to porosity. They might be rammed in each of two ways to get a given degree of hardness on the face of the mold, so that the effort could be made to discover whether there is any definite relationship between the compression as developed by squeezing and compression as developed by jarring or ramming. Possibly Mr. Batty has some data on that. If he has, I think it would be quite interesting.

MR. HALL: Mr. Batty called attention to a point that can hardly be over-emphasized, that the gate is the most important part of a mold. The steel runs through the gate the entire time the mold is being filled, the gate is subjected to the heat of the hottest steel for the longest time, and particles of the gate wall torn off and going into the casting certainly make trouble. But now Mr. Batty adds what, to me at least, is quite new, this sand sponginess. Some of the gas holes in steel castings, Mr. Batty says, are due to sand torn off the gate or the mold near the gate, and carried along with the steel, forming a point where gas tends to evolve. That seems to me to be one of the most interesting points brought out in the whole paper.

CHAIRMAN MELMOTH: I think we all know that we repeatedly come across castings that are unusually rough, eroded at the gate and definitely porous locally in the casting itself. I have seen that in every steel foundry I have ever been in, yet not necessarily in sufficient quantity to condemn a whole heat or for one mix of sand. Such sand sponginess is due, very possibly, to the physical action of the trapped sand in releasing gas which would otherwise have stayed in solution. I do not think that is definitely new. I would like, if possible, to call on Mr. Gezelius to tell us a little about that.

R. A. GEZELIUS[5]: It is nothing new; in fact it has been recognized abroad for a great many years; in Europe, particularly France and Germany, where they are now using tile down gates to get away from eroded sand. One foundry in this country is also using it and is having good results. I first heard of it two or three years ago, so it is not really a new problem. However, over there as here, the cause of porosity is still a matter of supposition, no one has definitely proved that it is caused by sand, the only fact they have is that these tile gates do eliminate part of it.

CHAIRMAN MELMOTH: Will you pass an opinion as a scientist on the rectitude of believing that the solid distributed through a liquid containing a gas in solution would become a nucleus for the release of gas from that solution?

MR. GEZELIUS: I think that the sand grain disintegrates. Sand is only silicon dioxide; if it breaks up, there is some oxygen given off. The action may be similar to saturated solution of chlorine when a solid particle is dropped into it.

MR. BATTY: But the blow holes are absolutely bright and spherical

[5] Division of Physical Metallurgy, U. S. Naval Research Laboratory, Washington, D. C.

in shape. The amount of oxygen present may not be enough to oxidize the entire surface.

MR. GEZELIUS: Once a small blow hole like that starts, it spreads easily by taking other gas from the metal itself. That is only my opinion, I have no definite facts.

MAJOR BULL: It just occurs to me to correct a mistaken impression that I think Mr. Gezelius had. Apparently he surmises that the practice of using tile, as he expresses it, or in other words, hard baked sand or similar material for gates, is new in this country. That practice has been used in America for a great many years, and we all recognize the fact that it is highly desirable to form a resistant gate. It is usually the gate that gets the maximum punishment of the mold.

MR. GEZELIUS: I did not mean to say that it was new here, but I do not know of any foundry here that uses it in standard production. There are foundries abroad that use tile down gates every mold they make. They buy tiles in 6-in. lengths and fit them together for deep molds.

MR. HALL: What I meant to imply was that idea that some gas blow holes are due to entrained sand rather than to gassy steel is new in discussions before the American Foundrymen's Association. It may have been brought out here before, but if so I have never heard of it.

CHAIRMAN MELMOTH: The real point at issue on the paper is the question of porosity due to sand entanglement. Now, bring it down to its practical plane for any further discussion and let us forget for a moment that possibility of some physical action which releases gases. Will some practical foundryman tell us whether or not he notices that castings badly eroded, particularly at the gate, have a definite tendency to local porosity?

C. W. BRIGGS[6]: I do not believe that it is necessary for sand to disintegrate to cause the formation of gas; there are plenty of instances where non-metallic particles act as catalytic agents, and it is possible that this particle of sand acts as a catalytic agent or carrier in gas evolution.

W. C. WOODWARD[7]: I would like to ask Mr. Batty, whether this fault of porosity occurs principally on the cope of the casting and, if it occurs, usually very close to the skin of the casting, or whether it is in the nature of a deep seated blowhole?

MR. BATTY: I will reply first to Mr. Woodward. As a rule, this manifestation which I have called sand sponginess, is just under the skin of the casting and may be exposed by a light surface cut. I have been able to collect from the bright spherical cavities sufficient of the fine material within the blow holes to identify such material as being largely silica.

Generally this sand sponginess occurs near an upper surface of a casting though I have seen it quite low or on vertically disposed faces. I am inclined to believe that this form of unsoundness is caused by

[6] Division of Physical Metallurgy, U. S. Naval Research Laboratories, Washington, D. C.

[7] George H. Smith Steel Casting Co., Milwaukee, Wis.

erosion of sand grains from the gate, where there is no remanant solidified envelope of metal, such grains being carried forward and coming to rest, at the moment the mold is filled—or slightly later by levitation—in contact with an already solidified skin at some part of the casting relatively remote from the gate.

With regard to Mr. Briggs' proposition that this sand sponginess may be the result of the catalytic action of entrained grains of sand, I would say that originally I entertained the same idea but that later I was persuaded to believe it might more correctly be attributed to the simple physical action of a solid on a saturated solution. It does not seem particularly to matter whether the action is catalytic, physical, or chemical; the results are undesirable in steel castings and the main point I wish to make is, that this form of defect appears most likely to originate at the gates and, for this reason, I advocate the production of special gate cores as a safeguard in the production of steel castings.

It must be admitted that I have seen many instances of embedded grains of sand in machined castings, such grains of sand being closely embedded in the steel and not associated with a gas cavity. This fact may promote the idea that steel in a certain condition is immune from the particular unbalancing effect of entrained sand where as other steel, because of its relatively large content of dissolved gases will exhibit this particular form of sponginess when sand is entrained and entrapped below the surface.

With reference to tile gates, I would say that it is well known that these are used in many foundries both in this country and abroad, but such tile gates are usually only applied to relatively large castings. The expedient of special core gates which I have suggested is one which is available to every foundry and it is a very simple matter to make up core boxes to produce the many varied types and sizes of gates which may be found necessary in a jobbing foundry producing a wide variety of steel castings.

Major Bull asked the question about comparative tests on identical castings in jolted molds and squeezed molds. I will say that I have made this test many times and on various types of castings. Although we did not secure accurate measurements of the degree of hardness of the mold faces, my impression is that the jolted molds had harder faces than the squeezed molds and in practically every case where the comparison was made, the jolt system produced better castings than the squeezer.

MR. WOODWARD: I hesitate to raise a question on this very excellent paper, but in paragraph 34 I think perhaps Major Bull really invited some discussion. I would like to call attention to paragraph 34 of his paper. I think certainly the author has some more information on that point. I am frank to admit that in my own experience, seeing those apparent pinholes adjacent to shrinks under the surface and perhaps adjacent to shrinkage cracks, I have been attributing these pinholes to a lack of feeding of the casting, and I would like to hear from Major Bull on that when he comes to close.

MAJOR BULL: Answering Mr. Woodward's question, I do not feel certain on that point. My impression is that at least the very small cavities that look like pinholes, which I have more or less frequently

seen in the corners of castings where there are draws, have not been actually caused by gas, but are cavities that I think usually take the form of a pinhole—not an elongated pinhole usually, but a rounded pinhole—merely as the result of some peculiar phenomenon which I do not pretend to understand, which caused the shrinkage to take that particular form. It may be that there is a direct relationship, but I have never been able to understand it, and if there are other theories on that point I should like to hear them discussed by those who have definite opinions on the subject.

CHAIRMAN MELMOTH: This paper by Mr. Woodward presents rather a new outlook on the causes of porosity. I think many of you will probably have already linked it to some of the remarks in the preceding papers. The authors of the preceding remarks, have viewed a similar phenomenon. Here is another viewpoint. The point that Mr. Woodward will have to contend with in dealing with this discussion, is that all steels contain inclusions and if all steels contain inclusions and inclusions cause porosity, all castings are porous because there must be at some time in their solidification the identical conditions which Mr. Woodward described as the causes of porosity. Logically, then all castings are porous and what we call porosity is merely when it is big enough for us to see it and it becomes a nuisance.

J. R. HOUSTON[8] (*Submitted in Written Form*): Mr. Woodward has certainly an unique view of the problem of porosity. An elaborate amount of detailed data has been accumulated from an accounting view point. It is such data as this that permits accurate analysis of our many problems, and the author is to be congratulated for his painstaking efforts.

Many of us have wondered at the periodical appearance, without apparent cause, of surface porosity in steel castings. All the controlable conditions would be normal, yet the trouble persisted. The writer is not informed if others, outside the Great Lakes region, experience these epidemics, but he has. However, no data were available, or made, to segregate it to specific seasons of the year.

It is well known that atmospheric humidity is particularly high in this region during the early summer months. It is quite reasonable to believe that condensation of moisture from the air could cause much of the trouble. In general, Mr. Woodward's tabulation shows major rejections during this period. High atmospheric humidity is not entirely confined to the early summer months in this region. A rough check with Government Weather Bureau at Milwaukee, Wis., shows an average monthly A.M. humidity of 84 per cent for February 1930, whereas the average for other years of the period, ranged from 73 per cent to 80 per cent. It will be noted also that February 1930 showed an unusually high amount of porosity rejections and almost equal that of the more generally humid months.

To carry the thought of the author further, it would be very interesting if daily relative humidity values were available. It might be suggested that a hygrometer, the cost of which is nominal, be placed in the foundry, taking readings daily, then comparing with the scrap report data. It is

[8] Harnischfeger Corp., Milwaukee, Wis.

quite possible that some relation can be established. If such a condition can be established, certainly the author will have accomplished much. Under any circumstances, it should not be passed over too lightly.

MR. SIMS (*Submitted in Written Form*): The seasonal variation in pinhole porosity shown by Mr. Woodward is most interesting. We shall probably have to blame it on the weather. Certainly the low points coincide with the time of year when we have the lowest absolute humidity and the peaks with the season of highest humidity.

The condition described in this paper of non-metallic deposits in pinholes of castings has been observed many times. These deposits occur not only in pinholes but in practically all holes forming under the cope skin of a casting. Sometimes, there is but a minute quantity and again it will half fill the cavity. Often, it shows evidence of having been fused, at other times just sintered. Some deposits have been identified as nozzle material from a bottom pour ladle and some as molding sand.

Some of these cavities are open to the surface while others appear to be definitely sealed off with a skin about 3/32 in. thick. The coincidence of these deposits and the cavities bears some relation to cause and effect.

Referring to paragraph 9, it is true that the ferrostatic pressure ceases when the gate freezes providing there is no riser on the casting. But then the liquid interior of the casting is sealed off and being non-compressible, the steel could not be replaced by gas cavities. It seems more logical to believe that these cavities are formed under the ferrostatic pressure of liquid metal in the gate or riser. This would mean that they form within a few seconds after the mold cavity is filled.

Dirt in the skin of a casting would not have to be molten to render the skin permeable to mold gases. The steel usually does not wet this surface dirt readily.

The experiments referred to in paragraph 13 would have been more conclusive had the molds sprayed with sodium hydrate been dried to compare with the unsprayed molds. The excessive moisture itself may have been sufficient cause for porosity.

MR. SIMS: In my paper I spoke of steel at the freezing point as being in all cases a super-saturated solution of gases; the super-saturation existing in various degrees. I had in mind this very condition Mr. Batty refers to in his paper, sand sponginess. I also suggested that the steel which showed the greater margin of safety against spontaneous ebulition of gas would probably be the least likely to be porous from extraneous causes, due to pouring conditions or mold conditions. Mr. Batty spoke of the deposits in those cavities, as being a fine powder. I have found it to be sometimes a fused material.

As to the mechanism of the formation of the blow around such deposits, several explanations might be offered. In a super-saturated solution, a foreign body could easily act as a focal point for the evolution of this gas. In this particular case, it is usually some material from the mold, and any sand, even though it had been previously warmed up to a considerable extent, would have a small amount of gas forming material present. Even a piece of pure silica would probably have some occluded moisture or gases which would come out only when heated to

a very high temperature, and as we can readily understand, a very small amount of solid material can make an exceedingly large quantity of gas. But we do not need a large quantity of gas, all we need is just a bare start, the tiniest bubble formed first to start the thing going; it will keep itself going after that.

I tried some experiments along that line; I took a small chill coil that had been calorized to prevent oxidation, filled it with molding sand and dried it at red heat. When this was inserted in a mold and steel cast around it there was an enormous blow hole above it. I also tried some more inert materials, a refractory that had been melted in an electric furnace, and which logically should not have any gas contained or should have the very minimum quantity of gas producing material. This formed, in some cases, a little gas but not anywhere near the amount produced when molding sand was forcibly held under the surface of the steel. This would indicate that the blow is produced from the sand itself.

MR. WOODWARD: Mr. Sims' comment on paragraph 13, that it would have been well had the second mold been sprayed with water so that the same amount of water could have been present, as was the case in the one sprayed with sodium hydrate, is obviously well taken. That experiment was made later, where one mold was sprayed with sodium hydrate and produced porosity; the second mold was sprayed with about the same amount of water, and in no case did porosity appear in the mold sprayed with water. However, the casting was badly scabbed. Mr. Sims' remarks with regard to the ferro-static pressure—I am not a physicist, but somehow I do not have the same mental picture of the freezing of a casting that Mr. Sims has. It seems to me that as the skin envelope of a casting commences to freeze, the interior metal which is quite liquid at first, is rapidly losing temperature, though not as fast as the surface, and as it loses temperature, it seems to me that it very soon reaches the stage where it is plastic and in that condition has practically no ferrostatic pressure. Going back now to Mr. Melmoth's comment with regard to the fact that if inclusions are always present in steel, and it is known that they are, then we must have porosity universally. Other papers attribute porosity to gas in steel and admit that all steel contains gases. Others attribute it to wet sand in green sand molds where there is always more or less water in the molding sand. It is my thought that porosity is due to reaching a certain combination of these causes, and when that combination is reached, and is so timed that the causes work in unison, we then have this particular type of porosity.

CHAIRMAN MELMOTH: I believe that porosity is not by any means such a serious characteristic of steel castings today as it used to be. That does not mean that we do not need papers of the present type, because we know that porosity still exists, and we know that we do not have it fully under control. That, carried to a logical conclusion, means that we do not know the exact reason for its occurrance; if we did, it would not occur.

Mr. Woodward, in replying to the discussion, has put his finger right on the main point which applies most aptly, *i.e.*, that a series of conditions

can cause porosity and that it is the coinciding of certain conditions that probably brings it about. No one can read these four papers without being sure that such was the case. I think that as we get to know more about it, we will probably find a shift from the attitude that ninety per cent of porosity as we now know it, is due to molds and cores.

I believe that a lot of extraneous effects dealt with in the papers by Messrs. Batty and Bull, made more extravagant, if you like, by conditions in steel which may be brought under control, and I believe that the aim of the steel making metallurgist for the steel foundry is going to have to be a less susceptible steel.

Whatever process we use, steel contains inclusions. Those inclusions are only beginning to be really studied and their effects on steel properties are only beginning to be thoroughly understood. Is it not equally possible that we may get a process of steel making which will render it less susceptible to all the effects brought out in these papers? Now, take another viewpoint, which would tend to confirm this opinion; variations in melting, although resultant analyses are identical, tend to have some bearing on the susceptibility of the steel in the foundry. We know that over-reduction in a basic electric furnace gives to that steel a most peculiar susceptibility to certain mold conditions. Why then, close the avenue of there being something in acid electric practice and open hearth practice which creates a similar susceptibility in steel?

A. C. JONES[9]: We all have had experiences in dealing with this problem of porosity that are just different enough for some of us to draw conclusions and to carry with us theories that are at variance with those of others.

One point developed today has been the difference found in various plants in susceptibility of the metal to porosity as it entered the ladle. In other words, in some plants, the factors that seemed to be most potent were such considerations as permeability, moisture and binders of the sands employed, or design of the casting, or the type of molding machine employed; but with others, the greatest emphasis has been laid on the metal itself, or on the furnace practice. However, an upset of practice either at the furnace or in the molding, results in an epidemic of porosity, which dumps overboard validity of past theories and former conclusions at the particular foundry concerned.

It has now come to be generally accepted that a good boil is necessary for the metal to develop the greatest immunity to porosity, due to what is felt as being the elimininationn of gases other than the oxides of carbon—probably hydrogen and nitrogen. In the electric arc furnace, it seems desirable to have the carbon lowered to about at least 0.15 per cent, which also assists to prevent too rapid a reduction of silicon from the slag in acid practice.

In some foundries, the nature of the scrap charged varied from time to time, so that without adding ore, vigorous boils were obtained. During that period, porosity was not a serious defect in the scrap record. But with a change to heavy clean scrap, including some dead-killed stock, the heats melted down with very little or no boil, and with any unbalanced

[9] Lebanon Steel Foundry, Lebanon, Pa.

condition in the molding technique or practice, serious porosity was experienced.

Carbon content is a factor in pouring green sand castings, my experience having indicated that the lower the carbon, the less susceptible to pinholes is the casting. To prove this some five years ago, employing a design of casting that had indicated sensitivity to porosity, several green sand molds were made and poured with regular cast steel of about 0.25 per cent carbon, with normal silicon and manganese, and also of a steel analyzing 0.04 per cent carbon, 0.03 per cent manganese and 0.50 per cent silicon.

Both steels were poured with about the same fluidity and with no aluminum additions, and were made in an Ajax high frequency induction furnace. The regular 0.25 carbon steel was quite porous, whereas the low carbon casting was free of porosity, even after heat-treatment had removed the outer skin.

Mention has been made by Mr. Batty and others, that the porosities found in certain walls of a casting, and particularly at fillets, are the direct physical or mechanical effects of the impinging of the mold gases into the metal, even through the hardened skin that has formed. To my own satisfaction, the illustration in the previous paragraph indicates that the answer is the iron oxide-carbon reaction which occurs following the charging of the metal with oxygen from the break-up of the steam into $H_2$ and $O_2$, the oxygen attaching itself to iron to form FeO, which in turn reacts thus:

$$FeO + C = Fe + CO$$

This gas cannot escape immediately due to the rapid cooling and therefore results in gas holes. In the above-mentioned comparison, if the cause of the holes had been explained as due to the forcing of gas from without into the steel mechanically, the low carbon casting should have developed the holes also, since the design, involving thin sections with fillets and re-entrant angles, offered plenty of opportunity for impingement of mold gases. The answer, I believe, is the lack of carbon, in the case of the porous-free casting, to react with the excess of iron oxide introduced into the metal in the mold.

With respect to the generation of gases initiated by silica grains, referred to in previous discussion as a catalytic effect, I am wondering if this were a general condition, why are we not troubled to a greater degree, than seems to be the case, with porosity as the result of projecting corners and cores, or by chills (discounting now the possibility of moisture or rust on metal chills)?

In comparing tendencies to porosity between foundries, recognition of the aluminum practice employed must be made. If enough is used, aluminum can "mask out" the otherwise obvious effects of contributing factors. Exception, of course, is to be made in the case of the gassy condition resulting from an over-reduced conditions as when considerable silicon has been picked up in the furnace on a very hot heat in acid practice, when of course aluminum is non-effective.

Aluminum is now coming to be considered a very desirable addition to steel because of its influence on grain size, which in turn affects the impact properties and ductility, not only at room temperatures, but also

with sub-zero conditions, as brought out in a recent paper* by Dr. C. H. Herty, Jr. Also, as was admirably expressed in the paper by Messrs. Sims and Lilliquist of several years ago, the condition of the steel with respect to nature of the contained non-metallics, prior to the aluminum addition, is of great importance to obtaining the maximum ductility.

In this connection, I had an interesting experience with medium-manganese steel some years ago. Metal from one heat to which 5 ounces of aluminum per ton had been added to the main ladle at the furnace, was divided into two portions, and poured into test bars. One set was poured with no further additions; the other set received metal treated with 32 ounces per ton additional. Tensile and impact values obtained with only a normalizing treatment of 1650 degrees Fahr. were

| | Aluminum, 5 Oz. per ton | Aluminum, 37 Oz. per ton |
|---|---|---|
| Tensile Strength, lbs. per sq. in..... | 96,000 | 94,750 |
| Yield Point, lbs. per sq. in..... | 56,500 | 60,250 |
| Elongation in 2 in., per cent..... | 26.0 | 21.9 |
| Reduction of Area, per cent..... | 51.8 | 33.2 |
| Charpy Impact (ft. lbs.) (Notched)..... | 9.8 | 17.7 |

A draw treatment, however, improved the Charpy values of the steel with low aluminum content, up to the level of the steel with the high aluminum addition.

The problem of the steel foundry today is to give consideration to all of these factors involved, so as to get castings which *firstly* are sound and *secondly* have the best all-around combination of tensile and impact properties. Aluminum, considered so objectionable in the past, is proving to be a friend when properly employed.

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* *The Effect of Deoxidation on Some Properties of Steel,"* TRANSACTIONS, American Society for Metals.

# Cause of the Incompatibility Occasionally Found Between Elongation and Tensile Strength of Malleable Iron Test Bars

By Enrique Touceda,* Albany, N. Y.

**Abstract**

*The author investigated the subject of the incompatibility between tensile strength and elongation which is occasionally found in malleable iron test bars, using over seven thousand test bars. He found that this incompatibility was always accompanied by a very small, characteristic surface defect in the rim of the fracture. No other defect was found that would account for the abnormally low elongation, and bars which were chemically or structurally defective were affected in all the tensile values. It is the opinion of the author that this defect is caused by a layer of very fine dirt from the sea coal facing. He states that neither the malleable industry nor the trade need feel the slightest concern about this incompatibility.*

1. The author was requested to submit his views on the subject outlined in the title of this paper, an assignment he was not reluctant in accepting because of the opportunity this offers to demonstrate to the members and the trade, through abundant data, that the incompatibility referred to is of very uncommon occurrence, and meaningless when its does occur.

2. It is regretable that, on occasion, it has been intimated by some, that the inconsistency in question can be accepted as indicating that malleable iron is not a uniform product. It will be shown not only that such a conclusion is unfair, but very unreasonable and unscientific on still broader grounds than one of inconsequence, because exactly the same incompatibility will be found to exist in the case of any cast metal test bar if tested as cast, if any surface defect is present on its gauge length that will act as a "stress raiser".

* Consulting Engineer, Malleable Iron Research Institute; Professor of Metallurgy, Rensselaer Polytechnic Institute, and Director, Touceda Chemical and Physical Laboratories.

Note: This paper was presented at a session on Malleable Iron Founding at the 1934 Convention of the A.F.A.

3. In comparing the results obtained in testing malleable iron test bars with those found for other metals, there are certain facts that should be kept in mind. Malleable iron test bars are tested as cast; they frequently are warped; and the cross-section of the gauge length is more often oval than truly circular.

4. On the other hand, the tensile test bars in the case of all other metal products are accurately machined, with the precaution taken to remove all visible tool marks from their gauge length by means of emery cloth or a fine file. Such are the usual directions given in the text books covering the preparation of tensile test bars and what the student is taught by his professor is a procedure that should be followed strictly.

5. Based upon the foregoing, it would be logical to assume that the majority of the testing engineers, in ignorance of certain peculiarities of the product that will be touched upon later, would deem it only fair and proper that a very generous handicap allowance should be granted when comparative tensile tests are made between malleable iron and other metals.

## CONDUCTS INVESTIGATION

6. Under the assumption that malleable iron test bars are free from a certain type of surface defect that will be described in detail, and for reasons that subsequently will be explained, the author does not see the need for any such allowance even though the bars are tested as cast; may be very badly warped; or may be out of round in their gauge length. While this may appear to many as being an extravagant statement and rank heresy, he has reason to know that he has not overshot the mark.

7. In 1931, the author carried through quite a thorough investigation to see if he could account for the fact that occasionally elongation was found to be out of line with ultimate strength. The results of three separate investigations were presented in bulletin form to the members of the Malleable Iron Research Institute.

8. The procedure adopted was to sort out from among the total number of bars received from all of the plants of the membership over a given period, those that showed the inconsistency in question. The first investigation covered a total of 1612 bars; the second 1553 and the third 3817. In these series of tests, the elongation was found to be out of line with the respective ultimate strength in 2.3 per cent; 1.73 per cent and 0.91 per cent of bars respectively.

9. After the first bulletin was submitted, it was suggested that certain molding precautions should be followed. It can be seen from the previous data that the bars that showed incompatibility were less in the second investigation than in the first, and still less in the third than in the second.

10. It further should be explained that, while the bars included those received from about 53 plants in operation during each interval, only 18 plants out of the total membership in the first investigation had one or more bars that required examination; 15 in the second, and the same number in the third. During these three investigations, there were 22 plants out of the entire membership whose bars were free from the defect mentioned.

11. A very careful examination of the fracture of the bars culled out for investigation, disclosed the fact that, without a single exception, all had a very small and characteristic surface

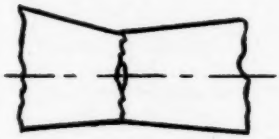

FIG. 1—SHOWING HOW DEFECT APPEARS AFTER RUPTURE OF TENSION SPECIMEN.

defect, which was very difficult to detect or locate except under magnification, at and to a certain depth in the rim of the fracture.

12. After some experience, it was noted that it could very easily be located without even a glance at the fracture, for it was found that if the broken ends of the bar were fitted tightly together, as in measuring elongation, a small oval shaped opening in line with the fracture served to position the check. An opening is formed because all of the metal at the section where fracture takes place has stretched except where the defect exists, with the result that it simply opens in the same manner as would obtain if a flat piece of rubber was stretched in which a small slit had been made crosswise of its longitudinal axis. When the two broken pieces of the bar are fitted together, the opening will look somewhat as shown in Fig. 1.

13. Once seen, the appearance of the opening cannot be mistaken for any irregularity at the outer edges of the fracture. Consequently, when a bar was broken that showed the inconsistency referred to, the two ends were fitted together and the position of the defect at once located. A note also was made of the position of the defect in the gauge length in respect to the fillets and

whether it was on that part of the gauge length that was in lowest part of the drag, in the highest part of the cope or located somewhere between these limits.

14. It might be well to point out that short of deep etching, which of course would be impractical, there is no way in which the defect could be discovered in a test bar as received.

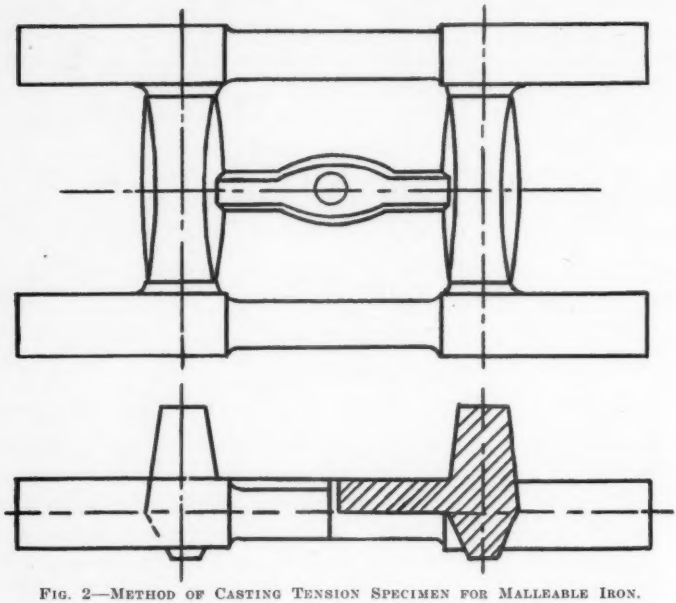

FIG. 2—METHOD OF CASTING TENSION SPECIMEN FOR MALLEABLE IRON.

15. Attention is called to the fact that during these three separate investigations, no other defect was found in the bars that could in any way have accounted for an abnormally low elongation, nor can the author conceive of one that would affect this property preferentially. When test bars are faulty due to chemical or structural composition or to interior defects, all of the tensile properties are affected. Inasmuch as the bars invariably are cast from a standard test bar pattern shown in Fig. 2, that has proved to be ideal for the purpose, the only unsoundness ever encountered is confined to a very small star-shaped spot that can be seen at the center of the fracture. As in all other metals, if the mold is poured with cold metal, under-surface gas holes will be present, but as the members are instructed to be sure that when

the mold is being filled the metal is on the hot side, an unsound bar due to cold metal is a rare occurrence.

16. The author is convinced that in the absence of the particular defect to which reference has been made, no incompatibility would be encountered. It has been shown that the percentage of bars having this defect decreased after proper molding precautions had been taken, which in turn means that if such a defect had been present in a bar as cast, but the bar not tested until after it had been machined, its elongation would not have been out of line with its ultimate strength, and, as will be demonstrated further on, the defect is not a metal but a molding problem.

17. To show as clearly as practicable the typical character of the surfaces of the defect under discussion, four fractures in which the defect was exceptionally deep were selected and photographed at a magnification of about eight diameters. These are shown in Fig. 3.

## SHOWS DEFECTS

18. It can be seen at once that the checks do not result from the local formation of a group of overgrown dendrites. If such dendrites were present, they would form a more or less deep, fan-shaped plane of weakness in the cross-section where they occur. Other evidence of the non-existence of overgrown dendrites is that such striations or curved ridges which are seen in the photographs of the check surfaces in Fig. 3 and which are common to the surfaces of all of those defects, are not at right angles to the cooling surface.

19. Without entering into detail, an analysis of the situation convinced the author that these defects are caused by the presence of a layer of very fine dirt of the consistency of dust from the sea coal facing or from other source or from an oxide film pushed forward in front of the opposite streams of molten metal from the two gates. The oxide film operates to form a parting at the junction where the two streams meet, and in this manner, very effectively prevents the welding of the metal on either side of this film.

20. As previously stated, a record was made of the position of the check in respect to its location on the fracture; whether in the lowest part of the drag, the highest part of the cope, or at an angle between these limits, and also its respective distance from the two fillets. It was found that 60.94 per cent of the checks were located at the lowest part of the drag and 14.06 per cent at the

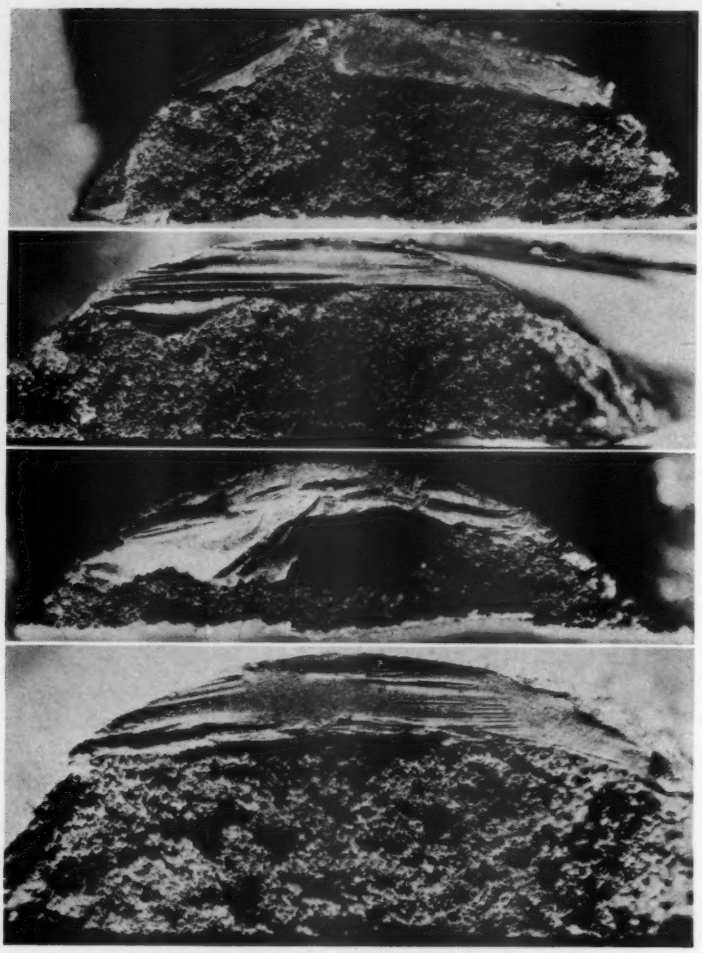

FIG. 3—FOUR SPECIMEN IN WHICH THE DEFECT OCCURRED, SHOWING APPEARANCE OF DEFECT AT A MAGNIFICATION OF 8X.

highest part of the cope. The remaining 25 per cent occurred at different locations between those limits.

21. An explanation will now be made to the statement of the author that, in the absence of the defect under discussion, he views with indifference whether the bars as received are warped, out of round, or have a gauge length eccentric to main axis.

22. In 1926, a bulletin was submitted to the Malleable Iron Research Institute from which the following is abstracted in condensed form:

> "Twenty-eight bars were cast from the same heat. Eight, which for convenience will be designated by the letter "*X*" were furnished as cast, while the gauge length of the other 20 bars, designated by the letter "*Y*", had been purposely ground in such a manner that their axis was as oblique as it could be made, to the axis of the grip ends. Test results are shown in Table 1."

**Table 1**

RESULTS OF THE TENSILE TEST

| | Average Ultimate Strength— lbs. per sq. in. | Average Yield Point— lbs. per sq. in. | Average Elongation— per cent in 2 ins. |
|---|---|---|---|
| 8 "*X*" Bars ..... | 55,900 | 38,313 | 20.75 |
| 20 "*Y*" Bars ..... | 56,522 | 38,585 | 21.45 |
| Difference in favor of "*Y*" Bars, Per Cent.. | 1.11 | 1.2 | 0.70 |

> "In only one case was the yield point of a "*Y*" bar lower than that of any of the "*X*" bars. In no case was the ultimate strength as low in the "*Y*" as in the "*X*" bars. The lowest elongation among the "*X*" bars was 17.50 per cent, while the lowest in the "*Y*" bars was 15.00 per cent, which bar contained a small defect at point of fracture. Two results came out the same. In the other 18 cases, the elongation was superior in the "*Y*" bars."

23. The author is in full accord with those who insist that a tensile test specimen should be symmetrical in respect to its longitudinal axis, and that its surface should be as perfect as is commercially practical. Also, that the higher the ultimate strength, the greater should be the importance of a rigid adherence to these details, and, as a further precaution, that equalizing grips should be used. It happens, however, that malleable iron is not only soft and ductile, but has an indescribable characteristic that apparently enables it to stand, with little difficulty, the deformation resulting from the complex stresses to which the metal in the eccentrically positioned gauge length is subjected. It is this very characteristic that enables the product to stand up so well in service when subjected to severe dynamic stresses and occasional over-loads.

24. In 1926, a series of 272 bars (Series 1, Table 2) from 68 different heats was tested. Each heat was represented by duplicate bar as cast (*X* bars), and duplicate bars that had been surface

ground true with the longitudinal axis of the bar (*Y* bars). Test results of this series of bars is given in Table 2.

**Table 2**

RESULTS OF TENSILE TESTS

| | Average Ultimate Strength—lbs. per sq. in. | Average Yield Point—lbs. per sq. in. | Average Elongation—per cent in 2 ins. |
|---|---|---|---|
| *Series 1* | | | |
| 136 *X* Bars ..... | 55,412 | 37,142 | 21.74 |
| 136 *Y* Bars ..... | 56,651 | 37,914 | 22.96 |
| *Series 2* | | | |
| 42 *X* Bars ..... | 55,679 | 36,833 | 21.67 |
| 84 *Y* Bars ..... | 57,347 | 37,882 | 23.11 |

25. Another set of 126 bars from 42 different heats (Series 2, Table 2) were tested but in this instance there was only one bar as cast (*X* bars) and two surfaces ground (*Y* bars) from each heat. Results also are shown in Table 2.

26. If the reader will refer to the requirements of A.S.T.M. Specifications Nos. 32510 and 35018, he will note that the average tensile properties listed above exceed even those of Specification No. 35018, and readily will understand why, from a purely practical standpoint, the author is rather indifferent to the condition of the malleable iron bars when tested.

27. Also, if reference is made to the same specification, the following will be noted under the sub-title "Retests": In case one of the retest specimens contains a flaw which results in the failure of the specimen to meet specifications, at the discretion of the inspector, additional test specimens from the same oven may be tested, or test specimens cut from castings may be tested".

28. Manifestly, the defect in question is a flaw, although it happens that it is one that is not practically discoverable until after the bar that contains it has been tested, and then only by an experienced man.

29. It follows, therefore, that the results of the tensile tests on the relatively few bars that were found to have contained a flaw among the 6982 tested, obviously would have been discarded had the series of tests been conducted for commercial purposes instead of for the reasons set forth in the foregoing.

30. Obviously, a defect of the character to which reference has been made can exist in a casting, but such are no more liable to be present in a malleable casting than in one made of steel or of

a nonferrous alloy, for, as has been shown, the trouble is not due to the metal but to molding operations.

31. In conclusion, the author would point out that neither the malleable iron industry nor the trade need feel the slightest concern due to the incompatibility between elongation and ultimate strength occasionally found in bars tested as cast, because the occurrence instead of being of the nature of an ailment, is what the French would call a "malade imaginaire".

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## DISCUSSION

H. A. SCHWARTZ:[1] (*Submitted in Written Form.*) It would seem that all those skilled in the testing of materials should agree with Mr. Touceda that surface defects in a test specimen of necessity decreases its apparent ductility. The author gives us statistics showing the greater prevalence of a particular type of defect in the drag, a point which should be instructive to those seeking to improve the physical quality of their test bars from a casting viewpoint.

It might be interesting to know why, if the fault is due to sea coal, sand, iron oxide or some other similar substance, it is not more prevalent in the cope rather than in the drag since all of these substances would float in liquid iron.

To those who might be desirous of comparing their performance to that noted by the author, it would be of interest to have a statement as to how low an elongation was accepted for the purpose of the present paper as being compatible with a given tensile strength. If any particular quantitative relation was used in deciding upon which particular specimens were to be considered as abnormally low in elongation, then the present commentator would be grateful for a statement of that relation for the guidance of himself and others.

It may not be out of place to point out that any rough test specimen will be inferior in elongation to a specimen of the same material whose surface is finished as carefully as Mr. Touceda has described. In this connection reference may well be made to Figs. 30, 31 and 32 of the Symposium on Malleable Iron Castings prepared jointly by the American Foundrymen's Association and the American Society for Testing Materials and presented at the 1931 meeting of the latter society.

Figs. 30 and 31 show tests on machined specimens; in the case of Fig. 30, the specimens were ground cylindrical before annealing, in the case of Fig. 31 they were turned afterward. Very great precautions were taken to make sure that the specimens remained straight during the annealing operation. It will be noted that these two figures show elongations falling in general upon a very smooth curve whereas the elongations of specimens tested without machining and plotted in Fig. 32 scatter very badly. This absence of uniformity is to be ascribed almost entirely to the difference in surface quality of the specimens even though these speci-

[1] National Malleable and Steel Casting Co., Cleveland, O.

mens were particularly selected to be as nearly perfect as sand cast specimens could be obtained.

Under the circumstances, from the viewpoint of acceptance testing, Mr. Touceda is no doubt justified in attaching but little importance to these surface defects provided they are identified as such. It is, however, unfortunate that, as quoted in paragraph 27, the specifications leave the matter of retesting to the discretion of the inspector. Therefore, if an inspector should choose to hold that such defects as described in the paper are not sufficient to warrant retesting then the foundryman is left without recourse. It would seem better if the specification were worded so that if a fault of a mechanical character is found, a retest would be mandatory. There is little doubt in the present commentator's mind that if we had mechanically perfect test specimens of malleable iron, accurate scientific conclusions as to the effects of various changes in composition and manufacturing methods would stand out much more prominently than they now do and there would be fewer differences of opinion. At present, we have not only the fault pointed out by the author but multitudes of smaller defects, such as roughness, which obscure the true physical properties of the material.

MR. TOUCEDA: The speaker has tried to make clear that, ordinarily, he believes a test bar should be as perfect as proves commercially practical and he has pointed out just why he is not greatly concerned in the case of malleable iron whether the test bar is or is not perfect.

Leaving out of consideration such ductile material as malleable iron, he would be very painstaking in connection with the preparation of a test bar for tensile test, and particularly careful regarding the finish of the surface of its gauge length. He recalls one instance of material that was to be sent to South America, but was rejected because of the fact that some of the tensile properties were a trifle lower than requirements. Upon examining the bars that had been tested, coarse tool marks were found on the surface of the gauge length, which upon being shown to the parties interested, the privilege was granted of testing other bars the gauge length of which were correctly prepared by running a Swiss file over their surface. The tests on these bars showed a creditable increase in tensile properties over the requirements and the shipment went forward. Numerous examples of this kind could be cited.

The speaker might point out that he has made tests on tensile bars of very soft steel prepared as were the ones of malleable iron and believes that, in this case also, the preparation of a test bar is not of great importance, but would insist that great care be exercised as the carbon content is increased or in the case of brittle materials.

H. W. HIGHRITER:[2] Two thoughts occur to me in this connection. The first has to do with the mechanism by which these defects in test bars are formed. The point has been raised as to why they should be on the bottom. It has been my thought that the reason for this may be that when iron cools to a temperature of approximately 2500 degrees Fahr., a stable film of iron oxide forms on its surface; if the temperature of the iron, as it is admitted through the gate, becomes lowered to 2500 degrees Fahr.,

[2] Westinghouse Lamp Co., Bloomfield, N. J.

such an oxide film will form, and will be rolled under the surface of the advancing iron, thereby lying on the bottom of the mold cavity. This phenomenon is easily observed in the case of aluminum. This explanation assumes that the foreign material is iron oxide, rather than seacoal or dirt, as suggested by Professor Touceda, an assumption that is supported by the wavy appearance of the defects.

Second, as to a possible way to avoid this in ordinary practice: in the present form of gating of test bars, as shown by Dr. Touceda's slides, the iron is admitted to the mold through two gates, and any loose dirt or iron oxide that may be formed is washed to the union of the two streams of metal and retained, generally in the most important part of the bar, the gauge length.

In one foundry with which I was connected, we made a considerable reduction in the number of defective bars of this type by changing slightly the method of gating. A strainer core was used and admitted the iron into only one feeder, and through that into the mold. The other feeder was enlarged somewhat to permit of its being used as a dead feeder. By this method the path of iron through the gauge length of the test bar is unidirectional. I think that is distinctly advantageous in reducing defects of this kind. Similar results can be obtained by tilting the mold during pouring.

LEO J. KELLY:[3] We have found in making tests on our bars, some instances of incompatibility as referred to by Mr. Touceda. With carbon about 2.05 to 2.08 per cent, we expect the test bars to have elongation around 25 per cent, but when bars of such analyses drop to 22 or 23 per cent, we customarily look for some defect in the bars, and usually find the condition brought out in Fig. 3.

E. E. GRIEST:[4] The request for this paper came from one of our Canadian neighbors who wanted to know why test bars from certain heats would show very different physical properties than test bars from substantially the same analysis. He also wanted to know why a number of test bars from the same heat, poured at the same time, would show considerable variations in the physical properties. It was for the purpose of bringing out some discussion on this subject that the paper was prepared.

[3] Fort Pitt Malleable Iron Co., Pittsburgh, Pa.
[4] Chicago Railway Equipment Co., Chicago.

# The Properties of Clays From Different Sources

By J. B. Blewett,* Wellsville, O.

**Abstract**

*The author discusses the properties of fire clays from various districts. Necessary properties listed are bonding power, plasticity when mixed with water, retention of shape under heated conditions, resistance to abrasion, fluxing and spalling. Effects of grain shape and size on strength are discussed and qualities of clays from various localities are compared. Effects of grinding and factors affecting placticity and firing shrinkage are reviewed. One table compares the chemical compositions of representative clays from various districts and another gives the firing properties.*

1. In a foundry, clays are chosen on the basis of delivered cost, and suitability for the services they must render. Different clays from a given fire-clay-producing district are customarily considered to be similar, but they will vary considerably as regards fineness of grinding, physical properties, firing behavior, chemical composition.

2. The general characteristics of fire clays from one district, as compared to those from another district, will be similar in some respects, different in others.

## Binding Power and Plasticity

3. One necessary property of all fire clays for foundry use, is the possession of the ability to develop binding power and plasticity when mixed with the proper proportion of water. Binding power is closely related to cohesion and to tensile strength, but differs from them in at least one important respect. The "binding power" is that property which enables a material to act as a cement or binding agent in uniting particles of other materials to which it is applied or with which it is mixed. The

* Ceramic Engineer, McLain Fire Brick Co.

Note: This paper was presented at a session on Refractories at the 1934 Convention of A.F.A.

term is used in a special sense as being that power which enables a plastic clay to be mixed with a considerable quantity of non-plastic material, and to produce a mixture which possesses plastic properties and ample tensile strength for the purposes for which it is required.

4. Another necessary requirement is that the impressed shape given a plastic, fire-clay-containing mixture will be retained when the mass is heated. The fire clay must be able to withstand medium to quite high temperatures, abrasion, fluxing action, spalling, heavy load, or combinations of these.

## EFFECT OF GRAIN SIZE AND SHAPE OF FIRE CLAYS

5. In clay mixtures, maximum strength is obtained with the use of irregular, angular grains of varying sizes, which can interlock freely; rounded grains cannot interlock properly, and produce a weak mass. The strength, in both the dried and fired states, increases with the fineness of grain; H. Ries[1] has shown (Table 1) that excessive fine materials decrease the tensile strength of dried clays.

**Table 1**

EFFECT OF GRAIN SIZE ON TENSILE STRENGTH (RIES)[1]

| Diameter of Grains Millimeters | Percentage of Grains of Each Size | | | | |
|---|---|---|---|---|---|
| | Clay No. 1 | Clay No. 2 | Clay No. 3 | Clay No. 4 | Clay No. 5 |
| 0.005–0.0001 | 87.96 | 30.64 | 22.00 | 44.00 | 59.00 |
| 0.01 –0.005 | 6.95 | 14.21 | 5.66 | 7.11 | 11.00 |
| 0.25 –0.01 | 3.00 | 5.58 | 26.55 | 24.35 | 14.70 |
| 0.5 –0.25 | 1.00 | 6.40 | 11.45 | 7.80 | 3.50 |
| 1.0 –0.5 | ..... | 42.95 | 33.44 | 16.35 | 11.40 |
| Tensile Strength— Pounds per Square Inch | 20 | 105 | 289 | 297 | 453 |

6. A. H. Dierker reported on "The Effect of Grain Size on Clay Bond for Molding Sands."[2] He employed a Lower Kittanning (Ohio Valley) plastic fire clay (10 per cent) milled with washed Ottawa sand (90 per cent) in a small muller type mill. The fire clay was sized into three grades of fineness. Results of the tests for bond strength are as given in Table 2.

[1] TRANS. AMERICAN CERAMIC SOC., vol. 6, p. 79 (1904).

**Table 2**

SIZE OF CLAY (DIERKER)[2]

| Time Milled Minutes | 8 to 20 Mesh | | 20 to 65 Mesh | | Less than 65 Mesh | |
|---|---|---|---|---|---|---|
| | Bond Strength | Moisture Per Cent | Bond Strength | Moisture Per Cent | Bond Strength | Moisture Per Cent |
| 3 | 96 | 2.6 | 149 | 2.68 | 140 | 2.65 |
| 6 | 153 | ... | 182 | .... | 170 | .... |
| 12 | 219 | 2.5 | 230 | 2.50 | 219 | .... |

7. Dierker stated that "these results would indicate that there is a distinct advantage in grinding clay to a certain degree of fineness, and little advantage in excessively fine sizing. In this particular case, there would appear to be little advantage in grinding finer than 65 mesh."

LOCATION OF FIRE CLAY DEPOSITS

8. The fire clays are principally from the coal formations of Pennsylvania, Ohio, Kentucky and nearby states, from the clay deposits of New Jersey, and from the lens and coal measure deposits of Missouri. Those employed in foundries are the plastic bond clays. They vary considerably in composition, with 45 to 70 per cent silica, 38 to 20 per cent alumina, from a fraction of a per cent to several per cent of fluxes, and 5 to 15 per cent of chemically combined water. When ground and mixed with water in the correct proportion, they develop considerable bonding power.

9. M. C. Booze,[3] in reporting work of the Refractories Manufacturers Association laboratory staff at the Mellon Institute of Industrial Research, University of Pittsburgh, stated that there is no relation between either chemical composition or fusion point and a clay's property of being open or dense burning. Two open-burning, plastic clays had silica contents of 44 per cent and 76 per cent, with fusion points of cones 32 to 33 and cone 30 respectively, while plastic clays which burned dense and then overfired, varied within almost the same limits. The clays in this latter group were characterized by comparatively high alkali contents, the range being from 0.97 per cent to 2.60 per cent, while dense firing plastic clays, which did not overfire, varied from 0.12 per cent to 0.49 per cent. The alkalis appear to have a very

[2] ENGINEERING EXPERIMENT STATION NEWS, Ohio State University, vol. 2, no. 3, June 1930.

[3] Booze, M. C., *"The Chemical and Physical Properties of Fire Clays from Various Producing Districts."* JNL. AMERICAN CERAMIC SOC., vol. 8, pp. 655-665 (1925).

pronounced effect upon both the fusion point and the firing properties.

10. The Lower Kittanning clay, found under Lower Kittanning coal, is the most important plastic fire clay produced in

**Table 3**

TYPICAL CHEMICAL COMPOSITION OF VARIOUS FIRE CLAYS

| Clay No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Silica ($SiO_2$)..... | 62.89 | 58.45 | 47.08 | 46.16 | 56.65 | 52.88 | 49.62 | 53.12 | 69.56 | 65.24 |
| Alumina ($Al_2O_3$).... | 21.49 | 26.95 | 36.12 | 35.04 | 36.33 | 33.61 | 33.15 | 31.16 | 20.34 | 22.34 |
| Ferric Oxide ($Fe_2O_3$). | 1.81 | 1.58 | 2.08 | 1.42 | 1.79 | 1.63 | 1.55 | 1.18 | 0.54 | 1.14 |
| Lime (CaO)..... | 0.38 | 0.30 | 0.86 | 0.27 | 0.35 | 0.22 | 0.13 | 0.12 | 0.25 | 0.20 |
| Magnesia (MgO).... | 0.56 | 0.49 | | 0.49 | 0.66 | 0.49 | 0.93 | 0.48 | 0.30 | 0.79 |
| Potash and Soda ($K_2O$ and $Na_2O$).. | 2.52 | 2.76 | .... | 0.64 | 1.23 | 1.39 | 0.97 | 0.49 | 0.26 | 1.71 |
| Titanic Acid ($TiO_2$). | 1.82 | 0.47 | .... | 2.44 | 2.95 | 1.28 | 1.56 | 1.76 | 1.64 | 1.36 |
| Ignition Loss..... | .... | 8.80 | 13.75 | 14.40 | .... | 9.02 | 12.10 | 11.26 | 7.54 | 7.96 |
| Water ($H_2O$)..... | 7.58 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Moisture..... | 1.16 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | 100.21 | 99.80 | 99.89 | 100.86 | 99.96 | 100.52 | 100.01 | 99.57 | 100.43 | 100.74 |

Clay No. 1 Lower Kittanning Clay, New Brighton, Pa.
Clay No. 2 Lower Kittanning Clay, New Salisbury, O.
Clay No. 3 Plastic Clay, Olive Hill, Ky.[4]
Clay No. 4 Soft Semi-Flint Clay, Kentucky.[5]
Clay No. 5 Westmoreland County, Pa., Plastic Fire Clay.[5]
Clay No. 6 Maryland Plastic Fire Clay.[5]
Clay No. 7 Missouri Raw Plastic Clay.[5]
Clay No. 8 Missouri Raw Plastic Clay.[5]
Clay No. 9 New Jersey Plastic Clay.[5]
Clay No. 10 New Jersey Plastic Clay.[5]

western Pennsylvania and along the Ohio River in eastern Ohio and the Panhandle of West Virginia. It is fine-grained. When properly ground, it slakes and mixes readily with water, and has high bonding power in the unfired and fired state. Typical chemical analyses are given in Table 3, columns 1 and 2. Drying and firing characteristics of the ground clay from New Salisbury, Ohio, are given in Table 4, column 2.

11. Many years ago, Seger of Germany pointed out that, of two clays of unequal refractoriness, the one of lower fire-resisting qualities may withstand the action of molten materials better if it is of high plasticity, as this makes it burn to a dense body at a comparatively low temperature. This is typical of the Ohio

[4] Ries, H., *"Clays, Occurrence, Properties and Uses,"* 2nd Ed., Wiley and Sons, New York, 1908.

[5] Booze, M. C., *"The Chemical and Physical of Fire Clays from Various Producing Districts,"* JNL. AMERICAN CERAMIC SOC., vol. 8, pp. 655-665 (1925).

Valley clays. The pores are closed, and such a clay resists the corrosive action of a fused mass better than the more refractory clay, which does not burn dense at as low a temperature as the

**Table 4**

FIRING PROPERTIES OF PLASTIC FIRE CLAYS FROM VARIOUS PRODUCING DISTRICTS

| †Clay No. | 1 | *2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Fusion Point Cone.. | .... | 29 | .... | 32-33 | 30-31 | 31-32 | 32 | 31 | 30-31 | 30 |
| Water of Plasticity, Per Cent..... | .... | 21.2 | .... | 16.8 | 19.4 | 34.1 | 32.5 | 17.9 | 30.3 | 37.3 |
| Drying Shrinkage, Per Cent..... | .... | 3.2 | .... | 13.0 | 19.5 | 24.8 | 32.1 | 14.1 | 22.0 | 33.9 |

Average Firing Shrinkage

| Degree Cent. | Degree Fahr. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1050 | 1922 | .... | 4.1 | .... | 11.5 | .... | .... | .... | .... | .... | .... |
| 1100 | 2012 | .... | 4.6 | .... | 13.7 | .... | .... | .... | .... | .... | .... |
| 1150 | 2102 | .... | 4.7 | .... | 18.2 | .... | .... | .... | .... | .... | .... |
| 1200 | 2192 | .... | .... | .... | 19.1 | 15.2 | 35.6 | .... | 18.6 | 13.6 | 23.8 |
| 1240 | 2264 | .... | .... | .... | .... | 18.3 | 36.4 | 32.7 | 18.9 | 15.4 | 27.9 |
| 1250 | 2282 | .... | 4.7 | .... | 19.1 | .... | .... | .... | .... | .... | .... |
| 1280 | 2336 | .... | .... | .... | .... | 16.3 | 35.9 | 33.2 | 20.7 | 17.2 | 29.5 |
| 1300 | 2372 | .... | .... | .... | 19.6 | .... | .... | .... | .... | .... | .... |
| 1320 | 2408 | .... | .... | .... | .... | 15.0 | 34.0 | 32.4 | 22.1 | 18.7 | 28.8 |
| 1350 | 2462 | .... | .... | .... | 20.6 | .... | .... | .... | .... | .... | .... |
| 1360 | 2480 | .... | 4.7 | .... | .... | 14.1 | 30.9 | 29.4 | 23.6 | 19.8 | 22.7 |
| 1400 | 2552 | .... | .... | .... | 20.1 | 13.0 | 26.3 | .... | 24.7 | 21.5 | 16.1 |
| 1440 | 2624 | .... | .... | .... | .... | 7.0 | 24.0 | 21.8 | 24.2 | 25.4 | 7.7 |
| 1450 | 2642 | .... | .... | .... | 23.9 | .... | .... | .... | .... | .... | .... |
| 1480 | 2696 | .... | .... | .... | .... | 2.3 | 22.2 | .... | 22.5 | 29.9 | 3.6 |
| 1500 | 2732 | .... | .... | .... | 26.0 | .... | .... | .... | .... | .... | .... |

Average Porosity

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1050 | 1922 | .... | 26.1 | .... | 29.0 | .... | .... | .... | .... | .... | .... |
| 1100 | 2012 | .... | 20.0 | .... | 26.6 | .... | .... | .... | .... | .... | .... |
| 1150 | 2102 | .... | 17.1 | .... | 23.3 | .... | .... | .... | .... | .... | .... |
| 1200 | 2192 | .... | 13.9 | .... | 23.4 | 18.3 | 7.6 | .... | 16.6 | 32.5 | 15.1 |
| 1240 | 2264 | .... | 10.5 | .... | .... | 12.0 | 1.6 | 1.4 | 15.8 | 29.6 | 7.4 |
| 1250 | 2282 | .... | 9.5 | .... | 22.6 | .... | .... | .... | .... | .... | .... |
| 1280 | 2336 | .... | 7.0 | .... | .... | 7.4 | 3.9 | 0.3 | 13.3 | 27.2 | 1.4 |
| 1300 | 2372 | .... | 5.5 | .... | 22.5 | .... | .... | .... | .... | .... | .... |
| 1320 | 2408 | .... | 4.0 | .... | .... | 4.3 | 4.8 | 0.3 | 10.5 | 26.3 | 3.2 |
| 1350 | 2462 | .... | 1.5 | .... | 21.4 | .... | .... | .... | .... | .... | .... |
| 1360 | 2480 | .... | 0.9 | .... | .... | 3.7 | 0.7 | 0.5 | 8.4 | 25.3 | 9.2 |
| 1400 | 2552 | .... | .... | .... | 20.5 | 2.6 | 1.1 | .... | 6.3 | 22.5 | 14.4 |
| 1440 | 2624 | .... | .... | .... | .... | 3.4 | 4.1 | 5.9 | 2.0 | 17.0 | 17.3 |
| 1450 | 2642 | .... | .... | .... | 16.9 | .... | .... | .... | .... | .... | .... |
| 1480 | 2696 | .... | .... | .... | .... | 6.3 | 4.5 | .... | 1.1 | 6.6 | 23.3 |
| 1500 | 2732 | .... | .... | .... | 13.5 | .... | .... | .... | .... | .... | .... |

* This clay was ground coarse.
† Refers to same clays whose point of origin is shown in Table 3.

first one, so a molten mass can enter the pore spaces between the grains. Some of the highest grades of fire clay require a more plastic material to increase their tensile strength, such additions being sometimes necessarily done at a slight sacrifice of refractoriness.

12. In the Olive Hill district in north-eastern Kentucky, and across the river in Ohio, in the Sciotoville area, associated with important coal measure flint and semi-flint clays, are plastic clays which usually run somewhat lower in silica and higher in alumina, somewhat nearer the $Al_2O_3.2\ SiO_2.2\ H_2O$ ratio of pure clay, than the plastic fire clays from the upper Ohio Valley. They are more open burning than the Lower Kittanning clay described above. Typical chemical analyses are given in Table 3, columns 3 and 4, and firing behavior in Table 4, column 4.

### First Quality Clay Districts

13. The great bulk of the so-called first quality clay is produced in the typical fire clay districts of the East, covering Clearfield, Westmoreland and Clarion counties, Pennsylvania, and the Mount Savage district of Maryland. These plastic clays are generally associated with the flint clay deposits. Chemical analyses of two of these plastic fire clays are given in Table 3, columns 5 and 6, and firing behaviors in Table 4, columns 5 and 6.

14. In the variety of its clays of all types, Missouri stands well up towards the head of the clay-producing states. The Missouri plastic fire clays occur at the base of the coal measures, and also as lens deposits. These plastic clays are usually hard when fresh, but disintegrate on exposure. Analyses are given in Table 3, columns 7 and 8, with firing behaviors in Table 4, columns 7 and 8.

15. Most of the high and medium grade clays of New Jersey occur in beds of various kinds and qualities, from sandy shales to quite pure kaolins, from white to black in color, from aluminous to highly siliceous, from lean to very plastic, from refractory to easily fusible. The bulk of the refractory clays which are used in New Jersey are low in their content of fluxes, and the products owe their good load-carrying capacity to this fact as much as to the incorporation of siliceous clays with the plastic bond clays. Chemical analyses of two New Jersey plastic clays are in Table 3, columns 9 and 10, with firing behaviors in Table 4, columns 9 and 10.

16. With regard to grain size, grinding so all will pass 1/32-in. screen openings is usually satisfactory. Grinding to a finer size increases costs. This is enough grinding to get these fire clays to a powder that slakes readily when used in reclaiming molding sands. This grind gives a graduation of grain sizes that develops ample bonding power and plasticity in mortars composed of bonding clay 25 per cent, old ground-up bricks, 75 per cent. As a clay for "ball stuff," a mixture of one part bond clay to five parts of ganister is usually satisfactory. For certain purposes, and with some types of clay, particularly those ground with a proportion of flint clay to increase their refractoriness, finer grinding may be desirable.

### PLASTICITY AND FIRING SHRINKAGE

17. The proportion of water required to develop the desired plasticity in all-clay or in clay-and-grog mixtures decides the drying shrinkage, the higher the percentage of water, the more the shrinkage. Firing shrinkage is dependent upon the nature and texture of the clay and the materials with which it may be mixed. Clays low in fluxes will be more open burning. Clays and mixtures high in silica will show little firing shrinkage.

### CHEMICAL COMPOSITION AND VITRIFICATION RANGES

18. According to their chemical compositions, clays will have long or short vitrification ranges, at low to quite high temperatures. Clays with considerable fluxing material (potash and soda, lime and magnesia) will vitrify at low temperature, and at higher heat will flux down, overfire, causing failure of the mixtures in which they are used. With more than a small per cent of lime and magnesia, the vitrification range, within which a clay is most useful, may be short.

## DISCUSSION

CHAIRMAN A. V. LUEN[1]: I should like to confirm Mr. Blewett's remarks with some of our experience with clays. We have always taken the position that the refractoriness of the clay means nothing so far as the resulting cleanliness of the castings is concerned. Mr. Blewett points this out when he quotes Seger as to the extent that lower fusing clays close, or in other words, present a tighter surface to the liquid metal, thus preventing metal penetration. A sandy clay having a higher refractoriness, will let the metal in. We, in the foundry, are directly concerned with clean castings and we want a material that will keep the metal out.

DR. H. RIES[2]: There is one fact which, it seems to me, we should not lose sight of, and that is the properties of clay which interest the foundryman and the ceramist are not necessarily the same. Clays for foundry use are mixed with sand in synthetic mixtures, and in that case, as pointed out by Mr. Blewett, the binding power is of importance, and the refractoriness may also be necessary to consider. There are other properties such as the fire shrinkage, density of burning and firing range, which although of great importance to the ceramist, can hardly be of equal importance to the foundryman, because the clay is so diluted with sand, that these properties do not make themselves felt to any marked degree.

I am pleased to note that Mr. Blewett has brought out the fact that there is no relation between either chemical composition and a clay's open or dense burning qualities. Too many deductions regarding the physical properties of a clay are often attempted from the chemical analysis.

May I call attention to the fact that my figures on the "Effect of Grain Size on Tensile Strength," quoted by Mr. Blewett, refer to the size of the individual grains of clay particles and sand, as determined by a fineness test, and not to a ground clay.

Opinions expressed regarding the effectiveness of fine grinding on the strength of a clay seem to vary, at least that is the conclusion I have drawn from replies to an inquiry which I had occasion to send out. It seems to me that this difference of opinion may be caused by variation in the character of different clays. Some clays slake easily, and even though coarsely ground may break down readily when mixed with water. Other clays are tough and do not slake readily; consequently it may be necessary to grind them fine to promote their slaking qualities and make them develop their plasticity and bonding power in a short time.

MR. BLEWETT: I heartily agree with Dr. Ries. I think that the point he made is more forcibly brought out in the pottery industry where clays are purchased with a definite rate of slaking. This is true particularly in certain bond clays which ordinarily have a quick slaking. In the paper, I more or less dodged that question because it brings in all

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[1] Bethlehem Steel Co., Bethlehem, Pa.
[2] Geology Dept., Cornell University, Ithaca, N. Y.

the kaolins and those types of clays which are ordinarily out of the price range for general foundry purposes. However, when it comes to bonding sand, there is no question that a clay that naturally slakes readily, will be of decided advantage. I wish to say also, that the Mississippi and Southern Illinois bonded clays are used in the foundry industry.

DR. RIES: Clays from Southern Illinois are strongly bonding and also very refractory. Those of Northwestern Mississippi are also highly refractory and have high bonding qualities as represented by their transverse strength.

R. P. HUER[3]: We manufacture fire clay brick in a number of plants in Pennsylvania and Kentucky and it has been our experience over a great many years that Kentucky clays are more dense burning than Pennsylvania clays.

N. J. DUNBECK[4]: Based on work that we did on 15 or 20 clays, we can make the statement that there is a sharp difference in the benefits that we get from grinding, depending upon the nature of the clays. This refers to the ordinary fire clays used in bonding sand.

In our tests, we measure the rate of slaking, the amount of free silica and the actual bond strength. We find a general relation between slaking time and content of free silica, the clays higher in free silica taking longer to slake down, apparently because they are harder.

When strengths of the clays are plotted, we find that the very soft, most plastic clays increase in strength with finer grinding almost in a straight line. This line does not rise sharply and we feel that above 20 mesh, there is little advantage in finer grinding, providing the foundry sand is to be thoroughly mulled. The strengths of the harder, more silicious clays rise sharply with finer grinding, giving us a pronounced curve.

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[3] General Refractories Co., Philadelphia, Pa.
[4] Eastern Clay Products Inc., Buffalo, N. Y.

# Permanent Mold Castings

By F. J. Walls,* Vassar, Mich.

**Abstract**

*The history of attempts to make permanent molds is almost as old as the art of casting metals, according to the author. In the first part of this paper, he describes the development of the present permanent mold machines used in the plant of the company with which he is associated. In discussing his subject, the author comments on some of the fundamentals of mold design, stressing the point that it is the controlling factor in mold life. One of the most important problems in the successful production of permanent mold castings, is the balancing of pouring and cooling times. By means of a chart, the author shows that permanent mold castings are divided into four types. In the latter part of the paper, melting practice and the structure and properties of the irons obtained are discussed. The author also gives a short resumé of what has been done in the casting of alloy irons in permanent molds and outlines the trends in the development of that process of metal casting.*

1. The history of attempts to make permanent molds is almost as old as the art of casting metals. Early in the history of metal casting, some inventive man evolved the idea that a mold might be made from clay or a like material, which could be formed and then baked to retain the impression. According to an article by R. J. Anderson and M. Edward Boyd, molding of this nature was practiced in the year 300 B. C. The next step in development was the use of stone molds hollowed out to the desired shape. Following this, mixtures of clay and stone were tried. Bronze molds followed in the order of development and were an improvement over the other types.

2. The discovery of iron led the foundryman back to sand molds, since none of the other molds would serve for iron casting.

* Metallurgist, Eaton-Erb Foundry Co.

Note: This paper was presented at a session on Cast Iron Founding at the 1934 Convention of the A.F.A.

Early in the nineteenth century, efforts were made to produce a permanent mold for iron castings. These attempts continued through the nineteenth and twentieth centuries with little success. The principal failing of all the molds was their inability to withstand repeated castings without burning out. This defect was due to an improper mold coating. Every type of coating was tried but with little success.

3. In the early years of the twentieth century E. A. Custer developed a method that warranted the building of machines which carried multiple molds. These machines in making a complete cycle permitted the coating, setting of cores, pouring off, shaking out, and cleaning of molds.

4. The years that follow are filled with the history of patents and processes and the activity was productive of some success. As the production of automobiles increased, the demand for many small castings became enormous. Mass production of many small parts in sand was, and still is, expensive; therefore, with the widening front of competition and the narrowing price range, great pressure was brought to bear on foundrymen producing automobile castings.

## DEVELOPMENT OF MACHINES

5. The Holley Carburetor Co., Detroit, was actively engaged in supplying carburetors and similar parts to leading automobile manufacturers. Prior to the year 1922, this company had encountered some difficulty in obtaining castings which were impervious to gasoline penetration. Such a defect made their finished product worthless. To overcome this difficulty this firm began experimenting with permanent molds to obtain a dense metal structure. The results of these experiments was a mold of sufficient life to make this casting method economical.

6. The first molds were made to produce carburetor castings. These molds were mounted on hand operated machines, each machine carrying one mold which was opened and closed by a lever action. Following the first successful castings, came the period of mechanization. Turntable machines were developed on which were mounted 12 molds located radially around the center post. These first machines were cam operated machines. One-half of the mold was mounted to a fixed head and the other half to a movable head. The cam acted to open and close the molds as the machine

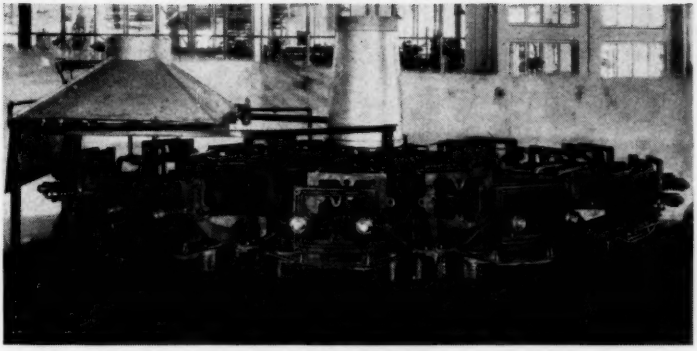

FIG. 1—PERMANENT MOLD MACHINE, AIR OPERATED.

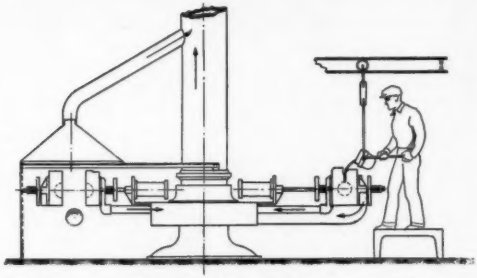

FIG. 2—CROSS-SECTION PERMANENT MOLD, AIR OPERATED MACHINE SHOWING COOLING ARRANGEMENT.

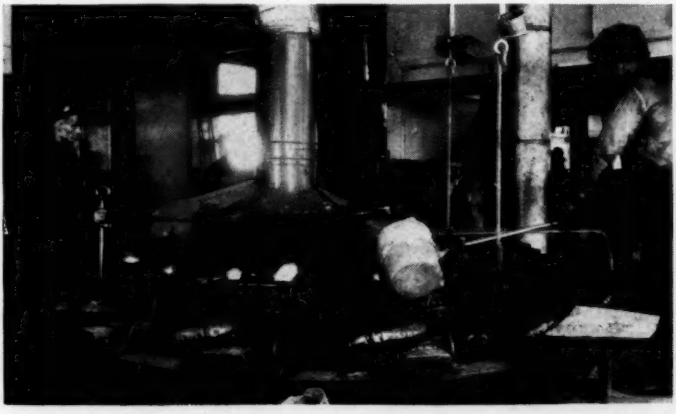

FIG. 3—PERMANENT MOLD. SMALL CAM OPERATED MACHINE.

moved around. The next type machine developed was a similar 12-head machine, but the opening and closing of the molds was done by double acting air cylinders, each mold powered by a separate cylinder. Continual development and refinement went on through the years following.

7. In 1931, the company with which the writer is associated became interested in the opportunities offered by this method of casting, and in February, 1932, purchased all patents and rights for the process from the Holley Company.

8. Our plant today contains the following equipment: Five large 12-head machines of the air operated type, shown in Figs. 1 and 2; four small cam operated machines, shown in Fig. 3, and 10 single head units, one type of which is shown in Fig. 4, for tryout and small production work. This together with the necessary cleaning and grinding equipment completes the plant. The capacity is 100 tons per day.

9. The patents covering this process are complete and cover the protective mold coatings, the method of casting permanent molds, cleaning and sooting equipment, permanent mold machines, cooling systems for machines, non-metallic molds, protective coatings for cores, process for casting a permanent mold in a permanent mold, risers and vent plugs for permanent molds. These and other patents cover the process as used today.

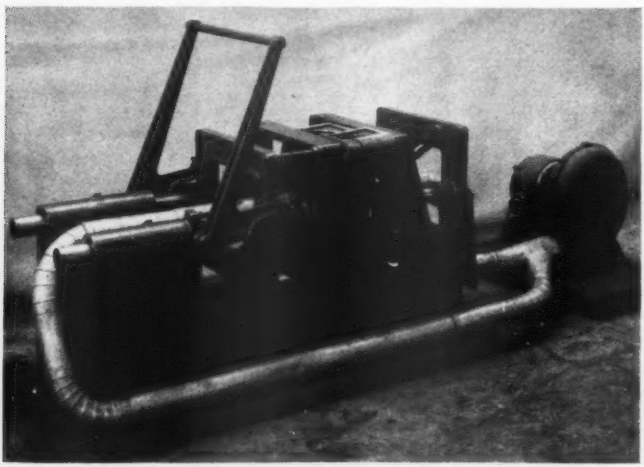

FIG. 4—SINGLE HEAD, HAND OPERATED MACHINE.

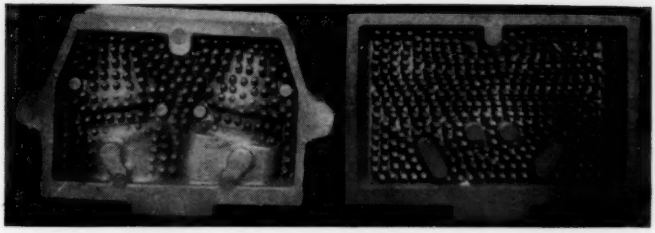

FIG. 5—REAR VIEW OF PERMANENT MOLDS SHOWING COOLING PINS.

10. Permanent molds, as designed at present, are standard in size and interchangeable. Eight different sizes are used. Four of the sizes are for small cam operated machines, one size will work on either size machine, and three sizes are for the air operated machines. The size and shape of casting determines the mold size.

11. The molds are designed individually to suit the casting. They are hollow backed with a face thickness that will vary from ¾ to 1¼ in., depending on the quantity of metal to be contained in the cavity. Cooling pins and bolt bosses are cast integral with the mold back, as shown in Fig. 5. Guide pin bosses are located on the sides of the mold to secure accurate matching.

12. As a general rule, the mold face is divided in the middle by the down sprue. Near the mold bottom, the down sprue merges with the runner which extends horizontally nearly to the edge of the mold as shown in Fig. 6. The cavities are placed above the runner, the size and shape of cavity determining the number. Cavities run from 1 to 18 in number and on an average a mold

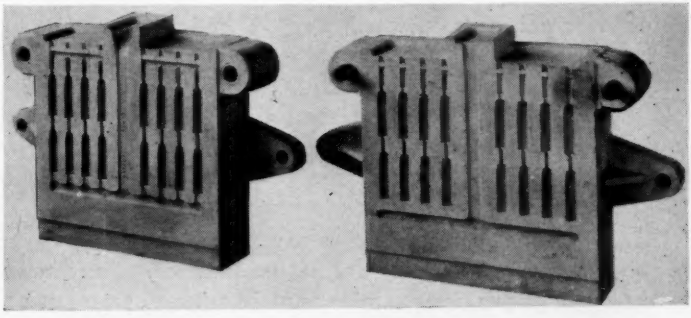

FIG. 6—A TYPICAL MOLD FACE SHOWING DOWN SPRUE AND RUNNER.

will contain four cavities, two on each side of the sprue placed one above the other. Above the topmost cavity are the shrink bobs and risers. The mold top surface is divided into three parts, each of which serves as a pool. The two outer pools are above the risers and catch any excess metal, while the center pool serves as a guide to the down sprue.

### PROCESS FOR PREPARING CASTING FOR PRODUCTION

13. The following is a brief resumé of the process which a new casting must go through before production is begun. A drawing is made to give mold design. From this, a wood master pattern is produced from which dry sand molds are made. The castings are poured with standard production iron of approximately the following analysis: 3.60 per cent total carbon, 2.50 per cent silicon, 0.08 per cent sulphur, 0.75 per cent manganese, and 0.30 per cent phosphorus. When cool, the castings are shaken out and sand blasted. The rough mold casting then goes to the machine shop where it is finished. Before leaving the machine shop, a lead dummy is cast to test the size of casting. The finished mold is coated with a refractory coating and then mounted on a tryout machine where it is checked for accuracy and the final adjustment of gates and risers made. When this is done, the mold is ready for the production of castings.

### IMPORTANCE OF CORRECT MOLD DESIGN

14. The primary controlling factor in the life of a mold is the correctness of design. By this we mean the proper balancing of the following factors: Correct location of cavities, proper thickness of mold back, good location of gates and risers, proper location of cores and vents. Assuming a good design, the mold will last from three to ten thousand pours. Disintegration begins with a small crack that soon washes into a large flaw and makes the mold worthless. There are some exceptions to the average life mentioned. However, these are molds containing many cavities and producing light weight castings. Such molds have good heat distribution and have no tendency to crack.

15. Designing of cores for permanent mold castings offers some problems that ordinarily are not encountered. Since these molds are non-porous, some caution must be taken to secure at all times a sufficient vent for both core and mold gasses. Whenever

possible, cores are designed so that one surface is open to the air. When this is not possible the core print is well vented and in extreme cases the mold face is given a relief cut for gas removal. A porous core of sufficient strength is obtained from the following mix: 160 parts bank sand, 90 parts sharp sand, and 5 parts of oil, giving an oil to sand ratio of 1 to 50.

16. One of the important problems in the successful production of castings by this process, is the balancing of pouring time to cooling time. These factors are related directly because using a turntable type machine makes it possible to shorten the cooling time by pouring late or too slowly. The pouring time is regulated, with reference to fast pouring, by the gate areas. To regulate the length of pouring time, the ladle is fixed on a ball and socket joint so that motion is restricted. Also the iron pourers are encouraged to skip molds when they are late in starting.

17. We consider the pouring times of such importance that a record is kept of them. In this way, it is possible to duplicate results where more than one mold is necessary to meet production.

**Table 1**

POURING RATES OF TYPICAL PERMANENT MOLD CASTINGS

| Cstg. No. | No. of Cavities. | Pouring Time—Minutes. | Wt. or Casting—Lbs. | Total Wt. of Metal—Lbs. | Rate of Flow to Cstgs.—Lbs./Min. | Total Rate of Flow—Lbs./Min. |
|---|---|---|---|---|---|---|
| 1 | 12 | 0.11 | 3.3 | 5.0 | 29.6 | 53.8 |
| 2 | 8 | 0.10 | 3.5 | 6.6 | 35.0 | 66.4 |
| 3 | 4 | 0.11 | 3.6 | 5.2 | 32.8 | 46.9 |
| 4 | 4 | 0.10 | 3.7 | 5.4 | 37.2 | 54.5 |
| 5 | 2 | 0.16 | 3.8 | 4.9 | 23.6 | 30.5 |
| 6 | 4 | 0.11 | 4.2 | 6.2 | 38.0 | 56.8 |
| 7 | 16 | 0.10 | 4.4 | 7.0 | 43.7 | 69.9 |
| 8 | 4 | 0.12 | 4.4 | 6.5 | 36.7 | 53.8 |
| 9 | 1 | 0.11 | 4.4 | 6.4 | 40.2 | 58.1 |
| 10 | 1 | 0.16 | 5.5 | 7.2 | 34.1 | 45.0 |
| 11 | 2 | 0.18 | 6.2 | 7.6 | 34.7 | 42.3 |
| 12 | 1 | 0.13 | 6.3 | 8.0 | 48.3 | 61.7 |
| 13 | 2 | 0.13 | 7.7 | 10.5 | 59.2 | 80.7 |
| 14 | 2 | 0.14 | 7.8 | 9.8 | 55.5 | 70.1 |
| 15 | 2 | 0.14 | 8.9 | 10.6 | 63.9 | 75.6 |
| 16 | 4 | 0.20 | 9.8 | 12.3 | 48.8 | 61.7 |
| 17 | 4 | 0.11 | 10.2 | 12.7 | 93.0 | 115.6 |
| 18 | 2 | 0.22 | 14.5 | 16.6 | 66.0 | 75.8 |
| 19 | 12 | 0.32 | 14.6 | 18.4 | 45.6 | 57.3 |
| 20 | 1 | 0.22 | 16.6 | 18.7 | 75.6 | 85.2 |

Table 1 is a compilation of the pouring rates of various castings in production at the present time. These castings are a typical cross section of the castings made by this method. They are arranged in tabular form according to the weight of salable castings per mold. You will note the table ranges from 3.3 to 16.6 pounds of salable castings per mold, from 1 to 16 cavity molds, and from 4.9 to 18.69 pounds of metal poured per mold.

18. Castings listed in Table 1 range from small castings ¾-in. in diameter to large wheels 10-in. in diameter and 1¾-in. thick. Also there are some flywheel castings listed which have a heavy hub, thin spokes and heavy rim. The figures given are average

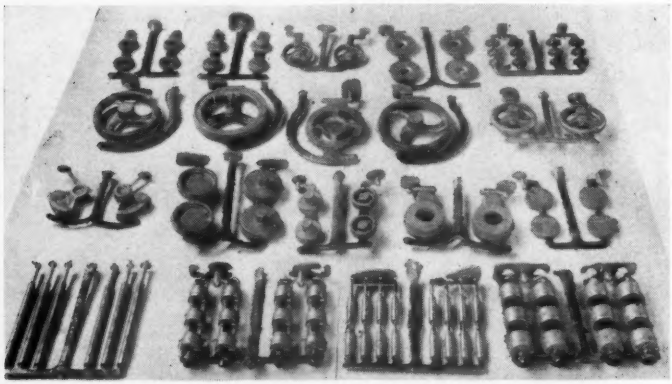

FIG. 7—GATES AND RISERS AS APPLIED TO VARIOUS PERMANENT MOLD CASTINGS.

values taken over a period of time. The variance that appears in this table is due to the shape of casting and not to poor application of gate size. Gates and risers on various castings are illustrated in Fig. 7.

19. Fig. 8 shows a graph of Table 1. The pouring rate of the casting in lbs. per min. has been divided by the number of cavities per mold, and the weight of salable castings per mold has been divided by the same figure. Thus the graph shows weight per casting plotted against pouring rate in lbs. per min. It will be noted that four distinct lines can be drawn from the origin point. It is interesting to observe that the castings are divided by this graph into four types. The point located below line *A* represents cored castings of medium thickness. The points on line *A* are cored castings of like sections. Between line *A* and *B*, are

castings having medium thickness, hub, and rims, and light webs connecting the two. The points on line *B* represents a flywheel casting with heavy hub, light spokes and heavy rim. The points on line *C* represent heavy cored castings. Between lines *C* and *D*, are more heavy sections, cored castings, and some heavy solid castings. Line *D* shows only heavy solid castings.

20. Cooling times taken on two individual permanent mold machines, are shown in Table 2. The cooling time measured is the time between the completion of pouring and the removal of the castings from the mold.

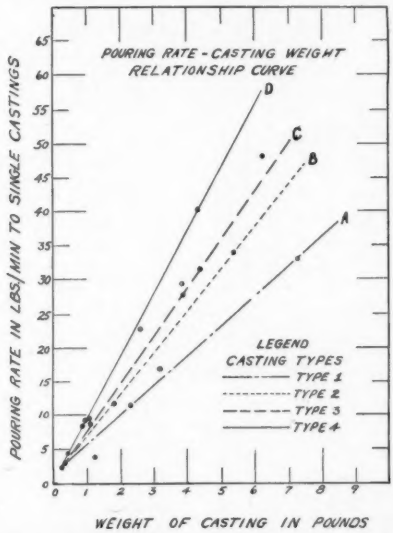


FIG. 8—POURING RATE-CASTING WEIGHT RELATIONSHIP CURVE.

21. At first glance, it might appear that the matter of cooling time would be unimportant when using permanent molds, but this is not the case. Lack of attention with respect to cooling times has a very harmful effect. If the casting is not cooled in the mold long enough, it is apt to develop small hairline cracks that appear only upon machining. If left in the mold too long, the casting tends to burn the mold out rapidly, and also, the casting hardness is decreased. To further adjust any variation due to cooling times and pouring temperatures, the castings are annealed to produce uniformity of physical properties.

22. Iron for the permanent mold foundry is melted in one of

two Whiting cupolas (sizes Nos. 4 and 6) specially lined with a bosh and deep well to produce high carbon iron. The larger cupola is lined down to 46 ins. in the straight with a bosh starting 36 in. above the tuyeres and tapering to a diameter of 40 ins. at the tuyeres. The tuyeres are continuous type, 4 ins. deep. The well

**Table 2**

COOLING TIMES OF TWO INDIVIDUAL PERMANENT MOLD MACHINES

| Casting Number | Readings in Minutes 1 | 2 | 3 | 4 | 5 | 6 | Average Time–Min. |
|---|---|---|---|---|---|---|---|
| | | | Machine No. 1 | | | | |
| 1 | 1.25 | 1.22 | 1.02 | 1.03 | 0.94 | 0.97 | 1.07 |
| 2 | 0.99 | 1.02 | 1.20 | 1.10 | 1.03 | 1.07 | 1.07 |
| 3 | 1.09 | 1.04 | 1.10 | 1.15 | 0.97 | 1.15 | 1.08 |
| 4 | 0.96 | 1.04 | 0.99 | 0.97 | 0.94 | 1.15 | 1.01 |
| 5 | 1.01 | 1.08 | 1.06 | 0.93 | 1.11 | 1.04 | 1.04 |
| 6 | 1.14 | 1.08 | 1.02 | 1.07 | 1.04 | 1.15 | 1.08 |
| 7 | 1.16 | 1.11 | 1.10 | 1.18 | 1.03 | 1.02 | 1.10 |
| 8 | 1.27 | 1.18 | 0.80 | 1.03 | 0.95 | 0.99 | 1.10 |
| 9 | 1.00 | 1.05 | 1.10 | 1.06 | 1.03 | 1.03 | 1.04 |
| 10 | 0.91 | 1.04 | 1.02 | 0.97 | 1.06 | 1.05 | 1.02 |
| 11 | 1.13 | 1.16 | 1.01 | 1.15 | 1.03 | 1.08 | 1.09 |
| 12 | 1.03 | 1.11 | 1.06 | 1.08 | 0.99 | 1.15 | 1.07 |
| | | | | | | Average | 1.06 |
| | | | Machine No. 2 | | | | |
| 1 | 0.41 | 0.42 | 0.44 | 0.43 | 0.33 | 0.46 | 0.41 |
| 2 | 0.38 | 0.40 | 0.43 | 0.41 | 0.41 | 0.45 | 0.41 |
| 3 | 0.45 | 0.40 | 0.46 | 0.39 | 0.40 | 0.38 | 0.41 |
| 4 | 0.44 | 0.44 | 0.41 | 0.41 | 0.34 | 0.31 | 0.39 |
| 5 | 0.42 | 0.35 | 0.43 | 0.35 | 0.40 | 0.38 | 0.39 |
| 6 | 0.42 | 0.41 | 0.48 | 0.38 | 0.44 | 0.39 | 0.42 |
| 7 | 0.38 | 0.43 | 0.37 | 0.38 | 0.40 | 0.41 | 0.39 |
| 8 | 0.43 | 0.36 | 0.45 | 0.37 | 0.40 | 0.42 | 0.40 |
| 9 | 0.44 | 0.40 | 0.45 | 0.39 | 0.38 | 0.40 | 0.41 |
| 10 | 0.35 | 0.39 | 0.38 | 0.49 | 0.39 | 0.39 | 0.41 |
| 11 | 0.38 | 0.40 | 0.35 | 0.40 | 0.34 | 0.35 | 0.37 |
| 12 | 0.41 | 0.41 | 0.37 | 0.38 | 0.37 | 0.45 | 0.40 |
| | | | | | | Average | 0.40 |

diameter is 44 ins. and the lower tuyere plate is 30 ins. above bottom doors. This cupola melts 8 tons per hour with a 1 to 8 coke ratio and 12-oz. blast pressure.

23. A charge consists of 1000 lbs. metal made up of 35 per cent pig iron and 65 per cent scrap, 125 lbs. coke, 35 lbs. limestone

and 1 lb. fluorspar. On account of the sprues being free from sand, small quantities of broken cores are used on each charge to produce a desirable slag. The iron produced has a temperature ranging from 2750 to 2850 degrees Fahr. at the spout as indicated by an optical pyrometer. The composition of the iron is held within the following ranges:

| ELEMENT | PER CENT |
|---|---|
| Silicon | 2.40 -2.50 |
| Sulphur | 0.100-0.115 |
| Manganese | 0.70 -0.90 |
| Phosphorus | 0.20 -0.30 |
| Total Carbon | 3.50 -3.60 |

## STRUCTURE OF IRON

24. In considering the structure of our iron we wish to refer to the following quotation:

> "There has been much propaganda relative to the value of a pearlitic matrix in gray irons. A pearlitic matrix is a very desirable characteristic in high quality irons, yet a pearlitic matrix is no guarantee of high strength or other desirable properties. The pearlitic condition in cast iron is a relatively stable one and persists over a wide range of composition and section thickness. In some cases the amount and condition of the graphite are predominant factors."[1]

25. The latter is true of permanent mold iron. Fig. 9a shows a typical microstructure of permanent mold iron in the as cast condition while Fig. 10a shows a typical iron in the annealed condition. Note the characteristic finely dispersed graphite and ferritic dendrites. This type iron, containing 2.50 per cent silicon and 3.60 per cent carbon, when cast in sand, has a very open fracture and under the microscope a very coarse graphite make up. It will show on an average 40 to 50 points harder (Brinell) when cast in a permanent mold than when cast in sand, if both castings are annealed 1640 degrees Fahr.

26. This increase in density, and consequently increased tensile strength, is probably due to two things: (1) as might be expected, a more rapid rate of solidification and (2) by an external pressure exerted by the mold itself during the expansion period of graphite precipitation.

[1] *Symposium on Cast Iron*, American Foundrymen's Association and the American Society for Testing Materials, p. 23, 1933.

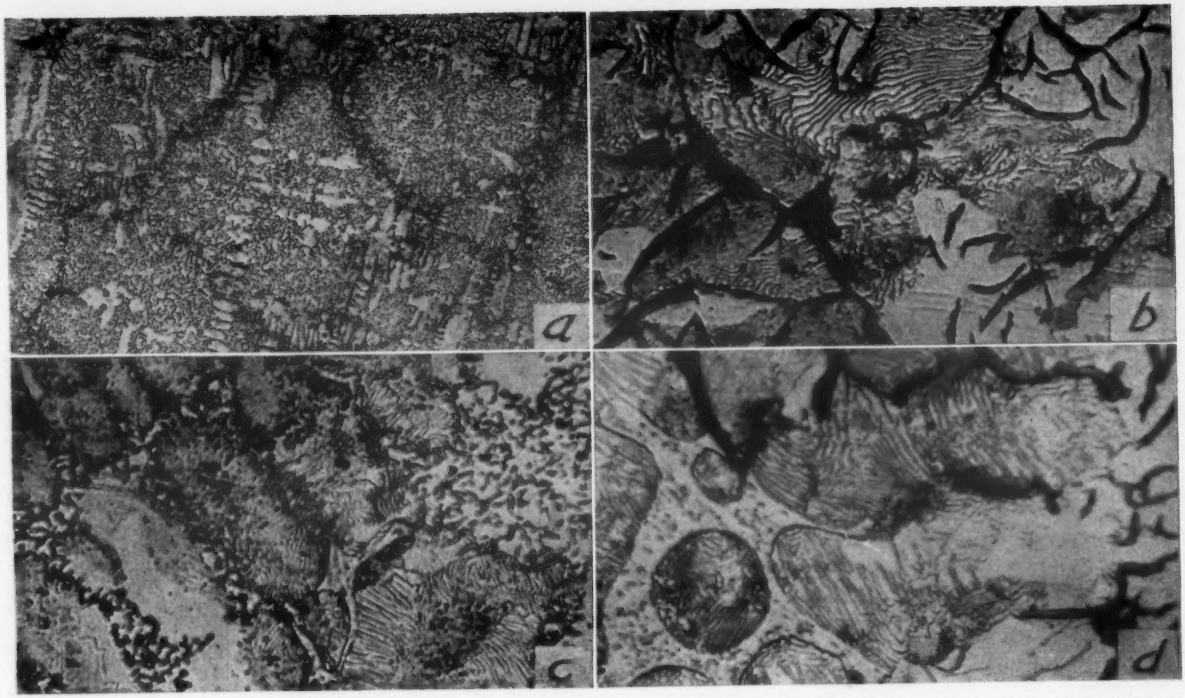


FIG. 9—PHOTOMICROGRAPHS OF REGULAR CUPOLA PERMANENT MOLD IRON ETCHED WITH 2 PER CENT NITAL. (a) AS CAST, 100X; (b) SAME IRON AS (a), 800X, SHOWING LARGE GRAPHITE FLAKES THAT SOMETIMES OCCUR; (c) SAME IRON, 800X, SHOWING TYPICAL GRAPHITE AND PEARLITE FORMATION; (d) SAME IRON SHOWING PEARLITE STRUCTURE AT 2000X.

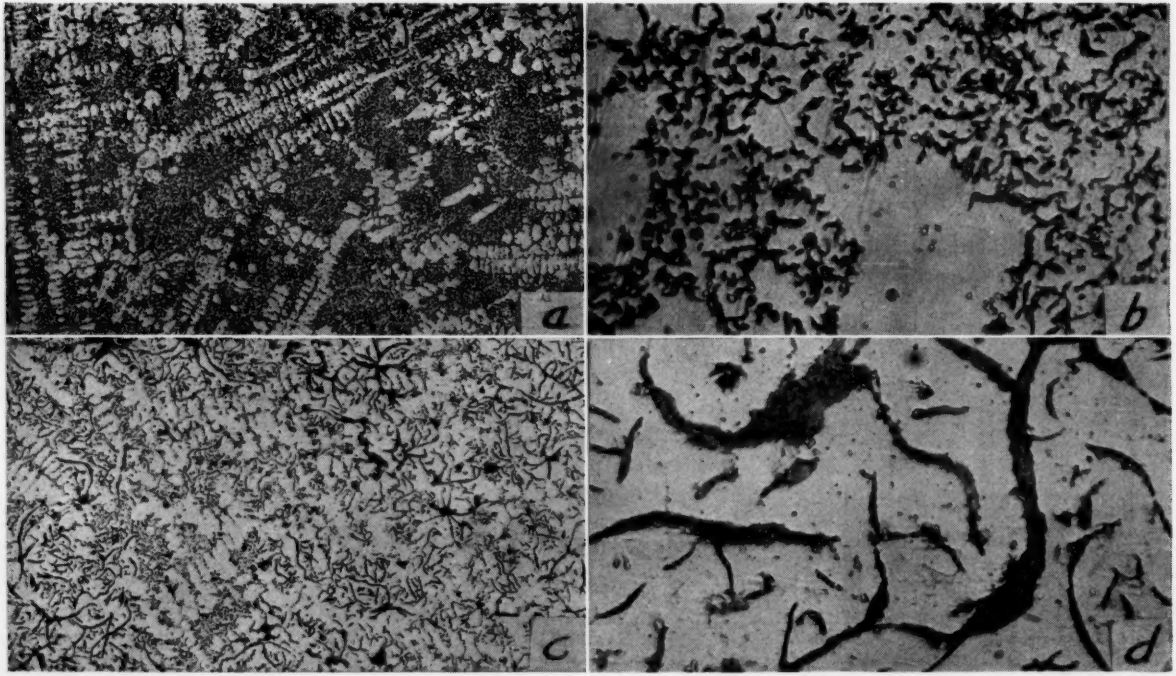


FIG. 10—PHOTOMICROGRAPHS OF REGULAR CUPOLA PERMANENT MOLD IRON ANNEALED, ETCHED WITH 2 PER CENT NITAL. (a) TYPICAL ANNEAL, 100X. (b) SAME IRON, 800X, SHOWING FINE DISPERSION OF GRAPHITE. (c) AN IRON, 100X, SHOWING A CONDITION THAT SOMETIMES OCCURS. (d) SAME IRON AS (c) BUT 800X.

## TRENDS IN DEVELOPMENT

27. There undoubtedly will be a development in the near future of automatic-mold temperature control and higher mold pressures which will produce an iron of even better properties than anyone has ever dreamed of. In fact, there seems to be a tendency to reverse the trend of yesterday, which was for lower carbon iron of high strength and go back to the higher carbon irons

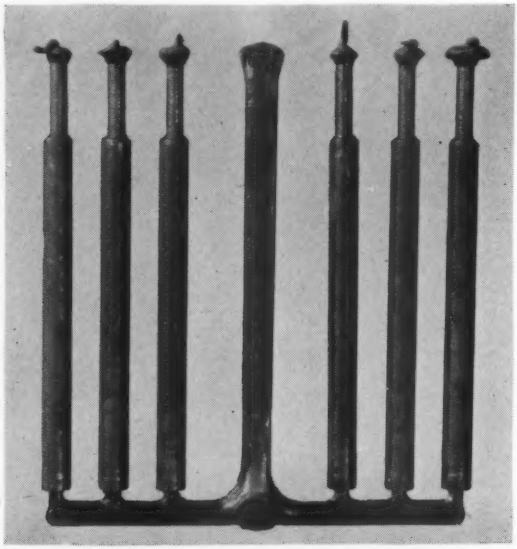

FIG. 11—SELF-FORGING EFFECT OF PERMANENT MOLD IRON WHEN CAST. NOTE THE EXTRUSION EFFECT AT TOP OF RISERS.

of equal if not greater strengths. This is being accomplished by super heating, by ladle graphitization, by alloy additions, and control of the solidification rate. Perhaps we should add for sake of argument the application of external forces at or immediately after the solidification point has been reached. This self-forging effect is illustrated by extruded metal at top of risers in Fig. 11.

28. To date, it has not been possible to completely eliminate the large graphite flakes, call them primary if you wish, as shown in Fig. 10C. It is known that this condition usually is produced by pouring cold iron into an exceptionally hot mold which invariably

## Table 3

### TESTS OF REGULAR CUPOLA IRON

| Bar No. | Quench[4] Temp. °F | Draw Temp. °F | Transverse[1] Lbs. Load | Deflection Inches | Tensile[2] Strength Lbs./in.² | Brinell Hardness | CHEMICAL ANALYSIS | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | SI | S | P | Mn | TC | CC | GC |
| 1[3] | ..... | ..... | 2939 | .269 | 25,550 | 170 | 2.44 | 0.114 | 0.290 | 0.83 | 3.63 | .... | .... |
| 2 | ..... | ..... | 3084 | .270 | 27,680 | 187 | 2.44 | 0.114 | 0.290 | 0.83 | 3.63 | .... | .... |
| 3 | 1500 | 1100 | 3623 | .243 | 34,960 | 207 | 2.56 | 0.108 | 0.291 | 0.79 | 3.60 | 0.26 | 3.34 |
| 4 | 1500 | 1100 | 3640 | .245 | 34,660 | 207 | 2.56 | 0.108 | 0.291 | 0.79 | 3.60 | 0.26 | 3.34 |
| 5 | 1550 | 1100 | 3600 | .254 | 39,000 | 229 | 2.42 | 0.115 | 0.300 | 0.78 | 3.54 | 0.28 | 3.26 |
| 6 | 1550 | 1100 | 3570 | .231 | 38,120 | 229 | 2.42 | 0.115 | 0.300 | 0.78 | 3.54 | 0.28 | 3.26 |

[1]Transverse Tests on 18″ centers.
[2]Tensile test bar was the standard 0.79 inch bar.
[3]Transverse and deflection on 1.125 in. diameter test bars corrected to standard 1.2 in. diameter bar.
[4]All bars given regular anneal. Bars held at heat 1 hr. before quench. 1 hr. draw.

## Table 4

### TESTS[1] OF REGULAR CUPOLA IRON

| Bar No. | Quench[2] Temp. °F | Draw Temp. °F | Original[3] Hardness | Quench Hardness | Draw Hardness | Tensile Strength Lbs./in.² | CHEMICAL ANALYSIS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | SI | S | P | Mn | TC | CC | GC | Ni | CR |
| 1 | ..... | ..... | 187 | ..... | ..... | 28,850 | 2.46 | 0.124 | 0.289 | 0.70 | 3.64 | .... | .... | .... | .... |
| 2[4] | ..... | ..... | 187 | ..... | ..... | 37,300 | 2.42 | 0.118 | 0.269 | 0.90 | 3.54 | .... | .... | 0.37 | 0.20 |
| 3[4] | ..... | ..... | 197 | ..... | ..... | 42,400 | 2.51 | 0.101 | 0.279 | 0.97 | 3.56 | .... | .... | 0.38 | 0.22 |
| 4 | 1550 | 1100 | 197 | 321 | 241 | 69,000 | 2.42 | 0.126 | 0.258 | 0.71 | 3.64 | 0.31 | 3.33 | .... | .... |
| 5 | 1600 | 1100 | 197 | 444 | 269 | 62,600 | 2.44 | 0.122 | 0.269 | 0.90 | 3.63 | 0.27 | 3.36 | .... | .... |

[1]The bars were not long enough for Transverse Tests. Tensile Tests were made on 0.875 in. diameter test bars machined to 0.505 in. diameter tensile bars.
[2]All bars given regular anneal. Bars held at heat ½ hr. before quench. 1 hr. draw.
[3]Hardness in Brinell values.
[4]Bars poured from Regular Cupola Iron with Nichrome addition to the ladle.

gives lower Brinell readings, and conversely, by pouring hot iron into cold mold higher Brinell hardness is obtained.

29. With the exception of bars 2 and 3 of Table 4, all physical tests were made of plain carbon irons. Table 5 shows physical properties obtainable an electric furnace iron of the medium carbon range by quenching and drawing. Figs. 12 and 13 are photomicrographs of heat treated irons cast in permanent molds. The iron shown in Fig. 12 is especially interesting from a high strength standpoint, having a high total carbon content and comparatively low combined carbon. This is further proof that the dispersion of the graphite and not the quantity, is the primary factor essential to high tensile strength values. It is also interesting to note that this is a straight cupola iron. The complete physical and chemical analysis of this bar is shown in Table 4, bar 4. Fig. 13 is an electric furnace iron of lower silicon and lower carbon content, heat treated as shown in Table 5, bar 3.

30. Photomicrographs C and D of Fig. 13 represent the same iron as shown in Photomicrographs A and B of Fig. 13, after oil quenching from 1550 degrees Fahr. and drawn at 1100 degrees Fahr. for one hour. The tensile strength has been increased approximately 40 per cent by this treatment and the resulting matrix is sorbitic.

## ALLOY IRONS

31. In the field of alloy irons cast in permanent molds, some work has been done with very satisfactory results. For example, a certain type of Ni-Hard iron, cast in sand, gave a Brinell hardness of 580 Brinell, while the same metal cast in permanent mold showed 780 Brinell. Stainless steels, heat resistant irons and white irons, such as tappets are being successfully poured in permanent molds.

32. It is interesting to know that nearly all branches of industry, such as automotive, refrigerator, marine, electrical, household appliances, etc., are large users of permanent mold castings. Figs. 14 and 15 show some of these types of permanent mold castings.

## ACKNOWLEDGMENTS

33. The author wishes to express his appreciation to the men of the organization with which he is affiliated for their support and to acknowledge gratefully the assistance of Kenneth H. Priestley,

**Table 5**

TESTS[1] OF ELECTRIC FURNACE IRON (LOWER CARBON)

| Bar No. | Quench[2] Temp. °F | Draw Temp. °F | Original[3] Hardness | Quench Hardness | Draw Hardness | Tensile Strength Lbs./in.² | CHEMICAL ANALYSIS | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | SI | S | P | Mn | TC | CC | GC |
| 1 | ..... | ..... | 197 | ..... | ..... | 45,400 | 2.11 | 0.088 | 0.237 | 0.74 | 3.10 | .... | .... |
| 2 | ..... | ..... | 197 | ..... | ..... | 45,150 | 2.12 | 0.089 | 0.234 | 0.73 | 3.11 | .... | .... |
| 3 | 1550 | 1100 | 197 | 477 | 269 | 63,400 | 2.11 | 0.071 | 0.240 | 0.75 | 3.14 | 0.33 | 2.81 |
| 4 | 1550 | 1100 | 179 | 477 | 269 | 60,300 | 2.28 | 0.098 | 0.230 | 0.82 | 3.25 | 0.47 | 2.78 |
| 5 | 1550 | 1100 | 187 | 477 | 269 | 57,050 | 2.25 | 0.102 | 0.282 | 0.82 | 3.44 | 0.27 | 3.17 |
| 6 | 1600 | 1100 | 187 | 477 | 269 | 60,500 | 2.25 | 0.088 | 0.236 | 0.78 | 3.45 | 0.35 | 3.10 |
| 7 | 1600 | 1100 | 179 | 477 | 269 | 55,050 | 2.34 | 0.095 | 0.235 | 0.84 | 3.37 | 0.47 | 2.90 |
| 8 | 1600 | 1100 | 179 | 477 | 269 | 59,700 | 2.25 | 0.089 | 0.258 | 0.78 | 3.37 | 0.45 | 2.92 |

[1]Bars are not long enough for Transverse Tests. Tensile Tests made on 0.875 in. diameter test bars machined to 0.505 in. diameter standard tensile bars.
[2]All bars given regular anneal. Bars held at heat ½ hr. before quench. 1 hr. draw.
[3]Hardness expressed in Brinell Values.

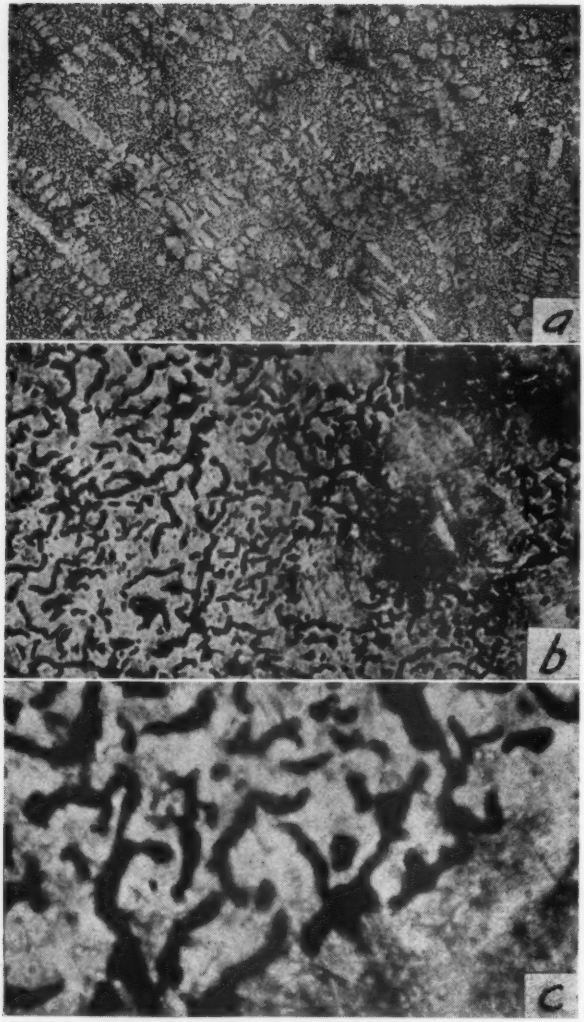


FIG. 12—PHOTOMICROGRAPHS a, b AND c SHOWING REGULAR PERMANENT MOLD IRON, HEAT TREATED; AT 100X, 800X AND 2000X RESPECTIVELY WITH 2 PER CENT NITAL ETCH. THE BAR WAS HEATED TO 1550 DEGREES FAHR., HELD FOR ½ HOUR, QUENCHED IN OIL AND DRAWN AT 1100 DEGREES FAHR. FOR 1 HOUR. THE TENSILE STRENGTH WAS 69,000 LBS. PER SQ. IN. THE CHEMICAL COMPOSITION, SILICON, 2.42 PER CENT; SULPHUR, 0.126 PER CENT; PHOSPHORUS, 0.258 PER CENT; MANGANESE, 0.71 PER CENT; TOTAL CARBON, 3.64 PER CENT; COMBINED CARBON, 0.31 PER CENT; AND GRAPHITIC CARBON, 3.33 PER CENT.

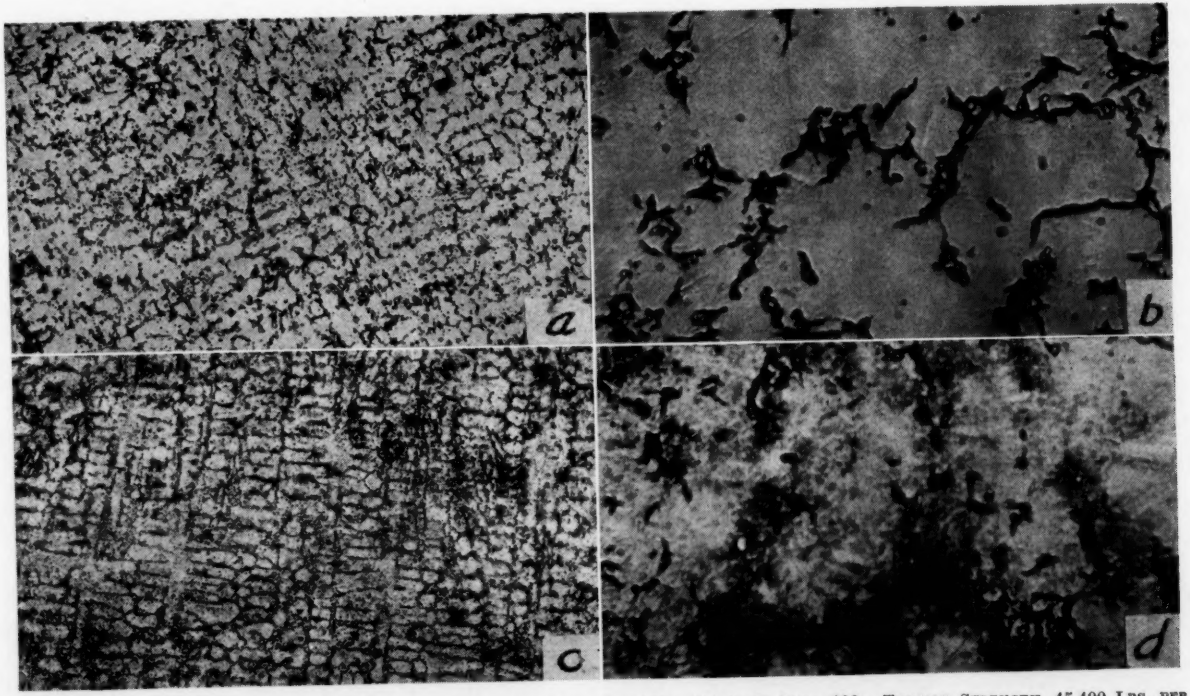


FIG. 13—PHOTOMICROGRAPHS OF ELECTRIC FURNACE IRON. (a) ANNEALED, 100X, (b) SAME IRON, 800X, TENSILE STRENGTH, 45,400 LBS. PER SQ. IN.; CHEMICAL ANALYSIS, SILICON, 2.11 PER CENT; SULPHUR, 0.088 PER CENT; PHOSPHORUS, 0.237 PER CENT; MANGANESE, 0.74 PER CENT; TOTAL CARBON, 3.12 PER CENT; (c) AND (d), SAME IRON AS ABOVE, HEAT TREATED; AT 100X AND 800X RESPECTIVELY. HELD AT 1550 DEGREES FAHR. ½ HOUR, QUENCHED IN OIL AND DRAWN AT 1100 DEGREES FAHR. FOR 1 HOUR. TENSILE STRENGTH, 63,400 LBS. PER SQ. IN.; TOTAL CARBON, 3.15 PER CENT; COMBINED CARBON, 0.33 PER CENT, AND GRAPHITIC CARBON, 2.82 PER CENT. ALL SPECIMENS ETCHED.

FIG. 14—VARIETY OF CASTINGS MADE IN PERMANENT MOLDS.

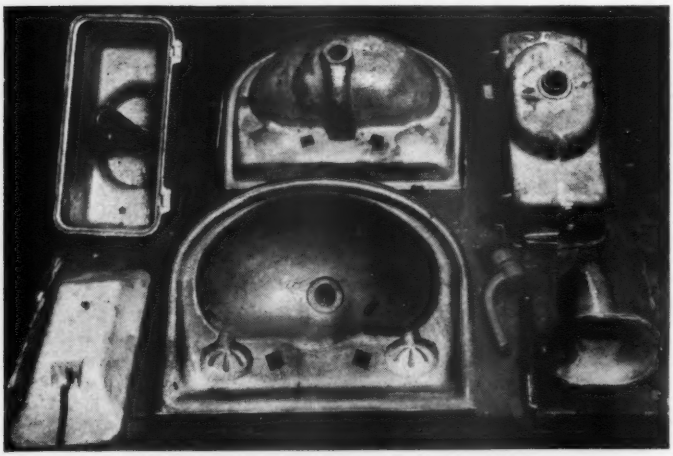

FIG. 15—SANITARY WARE CAST IN SPECIAL PERMANENT MOLD MACHINE.

metallurgist, and W. J. Moore, engineer, in the preparation of this paper, and to sincerely thank F. Marande, Wilcox-Rich Corp., Saginaw, and Prof. H. E. Publow, Michigan State College, East Lansing, for their timely suggestions and use of their equipment.

## DISCUSSION

H. H. JUDSON[1]: Fig. 10 shows a purging at the top of the casting. Does that purging show in every casting that you make?

MR. WALLS: Every one of the bars in Fig. 10 happened to show that. This purging depends on the restriction of the riser, also the gate restrictions and the amount of pressure that you have behind the mold heads. The fact will be appreciated that the casting, having a large surface area, has very much more push on the mold during this expansion. It requires heavier cylinders behind them to hold them together. We are working on some really large cylinders to get higher pressures to hold the two sections together. Undoubtedly you would get the extrusion on every cast.

MR. JUDSON: We get this condition in the large dry-sand molds, this purging up in the riser.

MR. WALLS: It is a good thing if it does not draw back and leave your casting with voids. On account of the pressure that we have and more rapid cooling, it does not draw back and leave cavities in a permanent mold casting as it is liable to do in the sand casting.

MR. JUDSON: You are in position to say that it is not the iron, and that you know definitely that it is not a melting condition?

MR. WALLS: It is a natural phenomenon that takes place in cast iron. In ordinary sand molds, it has a chance to expand in all directions and it does not come out through the top. I think that is right, but someone might not agree with me on that.

CHAIRMAN J. T. MACKENZIE[2]: That is a phenomenon that is connected with graphitization. You have to have a mold that is sufficiently firm to hold in the sides. I think nearly every test bar we have made with the old pit cast iron, which ran about 1.60 per cent silicon and 3.65 per cent carbon, showed that same thing on the top of the bar. It would not do it in the green sand mold because you do not have the pressure to hold it from expanding.

MR. WALLS: That phenomenon took place in 3.00 per cent carbon iron, too. There is one thing that I neglected to bring out and that was the difference in density, or Brinell hardness between the same irons cast in sand and those cast in permanent mold. Invariably in the fully annealed condition, there is an increase of hardness of 40 to 50 point Brinell with the permanent mold iron over and above that on sand cast iron.

MEMBER: Has anything been done to the melting conditions of the

[1] Goulds Pumps, Inc., Seneca Falls, N. Y.
[2] American Cast Iron Pipe Co., Birmingham, Ala.

iron for the permanent molds as against sand castings? I refer to carbon, or to other cupola conditions.

MR. WALLS: If I understand the question, you want to know what the melting conditions are and what effect they have. There is one condition that exists in permanent mold work in the cupola that does not exist in sand casting; that is, charging all clean scrap back into the cupola with no silica present. We add silica to our charge to combine with our limestone rather than cut down the amount of limestone used.

I have always been a firm believer in high slag volume, or the making of a large quantity of slag in the cupola to protect the iron as it comes down through the various zones. That is about the only difference, although to get the high carbons, we use a fairly deep well in our cupola and figure to carry in the small cupola, 36 ins. diameter, about 4000 lbs. of iron in the well.

MEMBER: Regarding the gas in the permanent mold, do I understand that 5000 lbs. pressure on the permanent mold would mean that there was some induced gas in the permanent mold? If so, does anyone know what harm that does, or whether it does no harm at all?

MR. WALLS: Of course, we get blow-holes in permanent molds the same as you do in the sand foundry. Fortunately, the percentage is somewhat lower. It is not a cure-all for all foundry troubles. If you mean do we get gas from the acetylene coating of the mold, then my answer is we get a certain amount, especially with core work. It is very essential when using cores in permanent molds, that you have the core open at some point to the outside, otherwise it is necessary to vent through the vent plugs, as I have shown. You have to provide for the elimination of the air or oxygen in the mold which is present when you start pouring and you have to have some exit for your combustible carbon.

HARRY RAYNER[3]: Is the coating on the permanent mold as vital as it used to be considered? Also, is there a difference in the refractory coating on molds for heavy castings as compared to the light?

MR. WALLS: Of course, on a heavy casting you do not get the mold life that you do on a light casting. On a heavy casting the mold life is probably 4000 pours, while on the small casting like the valve-stem, we get a life of 20,000 to 30,000 pours. When you multiply that by 16 you can see how many pieces we get out of one mold. The refractory coating is touched up only at night, after we are through pouring. We find that there might be a little abrasion, or that some of coating is knocked off when the workmen remove the castings from the mold, but those parts are touched up with a brush as necessary. Of course, the molds are coated with acetylene carbon after each pour, which is really a refractory coating.

MR. RAYNER: What is the base of the refractory material?

MR. WALLS: That material is patented. I do not mind telling you what it is. It is sodium silicate and a good grade of fine clay, pipe or any kind, finely ground. It is put on the face of the mold while it is hot. The combination of the two, the refractory coating and the carbon coating, are controlling patents in permanent mold work.

[3] Chrysler Corp., Detroit.

# Studies on Solidification and Contraction in Steel Castings-II—Free and Hindered Contraction of Cast Carbon Steel†

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**Abstract**

*This paper is the second presented by the authors before this Association on solidification and contraction in steel castings. The first presented before the 1933 meeting discussed the relation of solidification and contraction to the formation of hot tears. In this second paper the authors discuss their studies made on the free and hindered contraction of cast carbon steels with varying carbon contents. The contraction data are obtained on a bar that cools uniformly throughout. The contraction is hindered by means of springs and the resulting stresses and the amount of contraction correlated. The data are considered as to practical application and from the specific volume studies, an approximation is made of the solidifying contraction.*

1. A study of the contraction taking place in the cooling of steel castings from the solidifying temperature of the steel to room temperature, involves not only the consideration of the character of free contraction but that of hindered contraction as well. A thorough investigation of the free contraction of a steel casting does not necessarily portray the actual conditions encountered in the contraction of a commercial steel casting.

2. In the first report of this series,[1]** evidence was advanced which summed up the previous work on the contraction of cast

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** Superior numerals refer to articles included in the bibliography.

Note: This paper was presented at a session on Steel Founding held at the 1934 Convention of the A.F.A.

steel. It was pointed out that Körber and Schitzkowski[2] studied the contraction of cast steel employing apparatus similar to that used by Wust and Schitzkowski[3] in their study on the contraction of cast iron. From their experimentation, Körber and Schitzkowski concluded:

(1) The contraction characteristics of acid and basic steel were the same.
(2) The contraction was independent of the diameter of the bars.
(3) Approximately one-half of the total free contraction occurred before the bars passed through the critical range.
(4) The total free linear contraction was about 2.18 per cent.
(5) The hindered contraction was dependent on the nature of the mold resistance.

3. Although this work was admirably accomplished, there were several points that needed further study. These may be enumerated as follows:

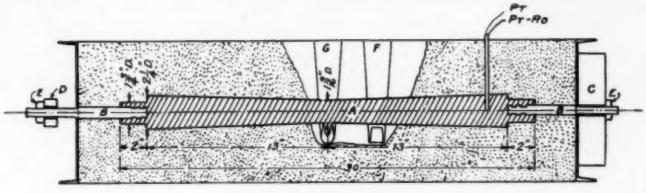
(1) Is the carbon content of cast steel responsible for variations in the free and hindered contraction?
(2) What is the nature of the loads that exist as compared to the amounts of hindered contraction?
(3) Would one-half of the total free contraction occur before the critical point if the critical points were made more pronounced?

4. From the data on hand, it seemed possible that the carbon content of cast steel would be responsible for variations in the linear contraction since many investigators[4] have shown, by their studies of the specific volume of steel from 20 to 1000 degrees Cent. (68 to 1832 degrees Fahr.) that the specific volume is, among other things, dependent on the carbon content. This condition was also found to be true by Benedicks, Ericsson and Ericson[5] from their results obtained in studying the specific volume of steel in the liquid state. Since the specific volume varies inversely with the contraction, it would logically appear that the carbon content would influence the amount of linear contraction. This condition, however, was not recorded by Körber and Schitzkowski, even though they used cast steels varying from 0.15 to 0.50 per cent carbon in their experiments.

5. There has long been a need for a quantitative study of

hindered contraction, for it is this type of contraction that is usually involved in commercial practice. Gaggers, sand conditions, casting design and flask construction are all factors to be considered in fixing responsibility for hindered contraction. It thus appears advantageous to study the loads that exist on the casting during the action of hindered contraction.

6. In order that test conditions would be similar to the conditions found in the production of a steel casting, studies on the contraction of cast steel were carried out on the cooling of a casting from the solidifying temperature to room temperature. Previous investigators have studied the cooling of liquid metal to room temperature. They used bars of a uniform diameter and, as was pointed out,[1] the bars did not cool at a uniform rate and thus the




A - CAST BAR
B - STAINLESS STEEL BOLTS
C - STEEL BLOCK
D - STEEL SPRING
E - NUTS
F - RELIEVING BLOCK
G - HORN GATE

Fig. 1—Design of Contraction Bar.

critical points were not pronounced. Conclusions as to the relative amounts of contraction before and after the critical point become much more accurate if the critical points are more pronounced. Thus, a bar that has a uniform cooling rate is more suitable for use in obtaining contraction data.

## Test Methods

7. The procedure used in collecting the data on the free and hindered contraction of cast steels with various carbon contents is given in the following paragraphs.

### (1) *Bar Design*

8. A bar design was developed with large ends and a small central section fed by a horn gate, as it was deemed necessary that the bar should cool uniformly along its axis. This design is shown in Fig. 1. A bar of this type was desired because then all portions of the bar would pass through the critical range at about the same

time and the data obtained would be more accurate than that obtained on a straight bar where portions of the bar are contracting and other portions are expanding at the same time.

9. The bar is 30 ins. long with a diameter at the center of $1\frac{9}{16}$ ins. (a cross-sectional area of 2 sq. in.) and a diameter at the ends of $2\frac{1}{4}$ ins. At each end of the bar, is a section $1\frac{3}{4}$ ins. in diameter and 2 ins. long. This section acts as a clamp on the stainless steel bolt and, of course, does not cool at the same rate as the remainder of the bar because of the chilling action of the bolt. This chilling effect does not extend much beyond the $1\frac{3}{4}$ in. diameter section, as a thermocouple placed on the axis of the bar at a distance of $\frac{1}{2}$ in. from the end of the bolt recorded the same temperature that was obtained by other thermocouples at other points on the axis.

(2) *Type of Sand*

10. The sand used is a synthetic green sand using No. 40 washed silica sand as a base and mixed in the following proportions by volume:

500 parts silica sand.
19 parts bentonite.
1 part Mogul binder.
5 per cent (by weight) water.

11. The mixture is mulled for five minutes and the following properties are obtained:

| | |
|---|---|
| Permeability | 180 cc./min. |
| Compression strength | 3.5 lbs./sq. in. |
| Shear Strength | nil. |
| Tensile Strength | nil. |

The sand is reclaimed after it has been used. The properties of the reclaimed sand are the same as those of a newly prepared sand.

(3) *Molding Procedure*

12. Steel flasks constructed of 5-in. channel iron 36 ins. long and 10 ins. wide are used as the mold containers. The sand is rammed lightly to a mold hardness number of about 50. A horn gate, varying from 2 ins. to $\frac{3}{4}$ in. in diameter, is used for the pouring gate. The $\frac{3}{4}$ in. section, where the steel enters the mold cavity, is much smaller than the contraction bar at this point and hence freezes before the bar, thus allowing very little feeding during the solidification of the bar.

13. A relieving block 1½ ins. square, shaped similarly to the horn gate is molded-in a short distance away from the horn gate. This block is removed from the mold and when the hindered bars contract the horn gate is able to move freely without being restricted by the molding sand. The surface of the mold cavity is not covered with a mold wash.

(4) *Assembling the Mold.*

14. A photograph (Fig. 2) of the mold ready for assembly, shows a stainless steel bolt protruding from each end of the flask.

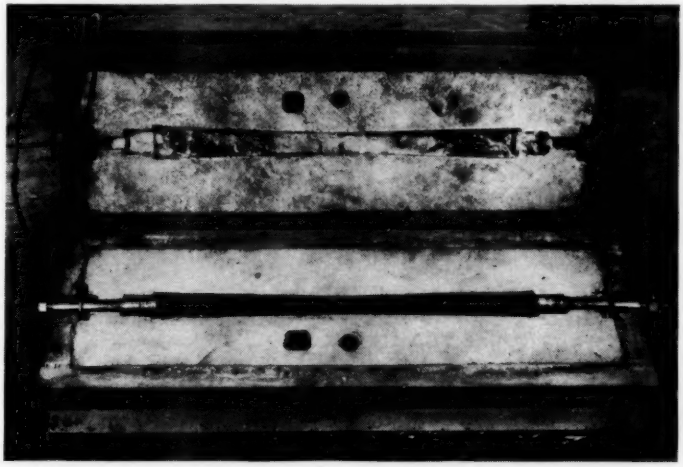


Fig. 2—Mold Ready for Assembly.

One bolt ties the bar down to the flask (Fig. 3) and the other is fastened to the flat steel spring (Fig. 4). The bolts are ⅞ in. in diameter and have a 4-in. shank and a 5-in. body. Two grooves ⅜ in. wide and ⅛ in. deep are machined in the body end of the bolt. This permits the metal, upon solidifying around the bolts, to have a strong grip on them. The chilling action is so great that the bolts do not fuse into the cast metal.

15. A small quartz thermocouple protecting tube is run through the cope of the mold, 1½ ins. from the end of the bolt that ties the cast bar down to the flask. This tube extends to the axis of the bar and the readings obtained by the platinum-platinum-rhodium thermocouple represent the temperature of the bar throughout the central 26 ins.

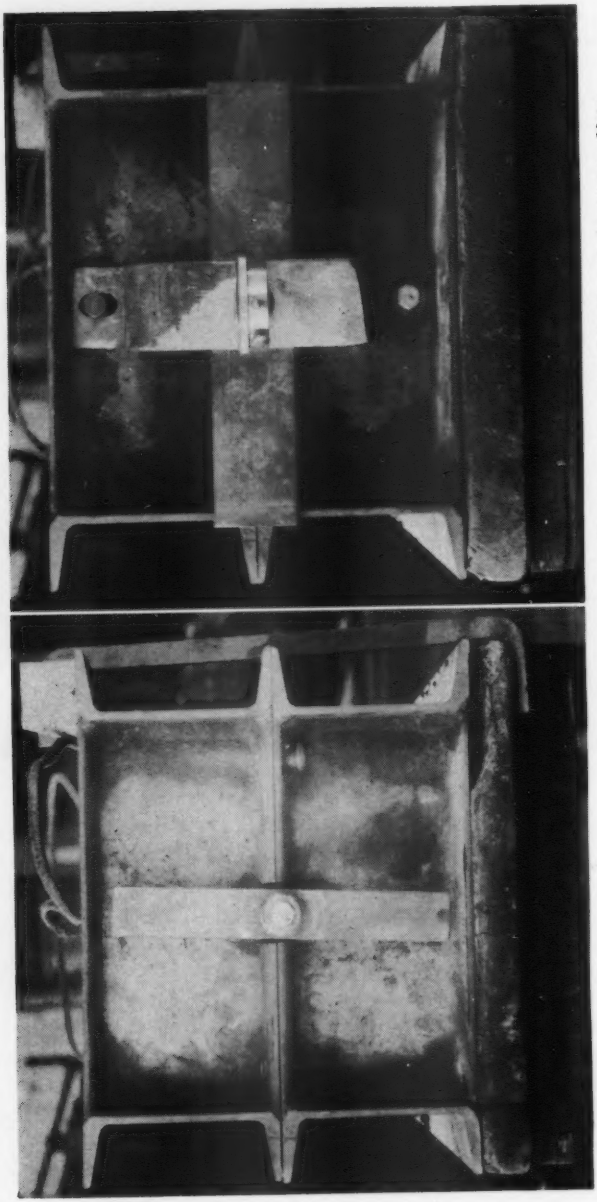


FIG. 3—(LEFT)—METHOD OF FASTENING BAR TO FLASK. FIG. 4—(RIGHT)—SPRING ARRANGEMENT ON ASSEMBLED MOLD.

16. The flat springs used were made out of $2 \times 10\frac{1}{2}$ in., heat-treated, spring steel and are of the following thicknesses:

"*C*" springs 7/8 in. thick
"*G*" " 9/16 " "
"*E*" " 3/8 " "

Ames dials, held by an arm bolted to the end of the flask are used for measuring the amount of contraction. A moving picture camera using a 16 mm. film operated by a Telechron synchronous motor records the amount of shrinkage and the temperature every 15 seconds. The temperature recorder is a pyro-millivoltmeter and

Fig. 5—Arrangement for Pouring.

has a temperature range of 0 to 1600 degrees Cent. (32 to 2912 degrees Fahr.). The Ames dials are graduated to 0.001 of an in. The complete set up is shown in Fig. 5.

17. It was found that to show the true free contraction, the bar must be free at both ends and that two Ames dials were required. The true contraction was not recorded if one end of the bar was tied down and measurements were taken with only one end contracting freely.

18. The runner box, which is used for convenience during pouring, is slotted at the base so that the excess metal will run out and not act as a feeding head or restrict contraction.

(5) *Type of Steel*

19. The steel is made in a 500 lb. per hour, Swindell, 3-phase, electric-arc furnace. The basic practice has been used entirely during the collecting of the data presented in this report. An attempt has been made to use steels, the compositions of which are comparable to those found in the foundry industry. However, to complete the data, steels with lower and higher carbon contents than those generally used in the industry have been investigated. In all cases conditions as to chemical analysis and steel making have been duplicated as nearly as possible several times so that the data obtained could be checked carefully.

(6) *Pouring*

20. The steel is poured from a tea-pot ladle so that slag has very little opportunity to enter the mold. The pouring temperature of the steel entering the molds is between 2880 degrees Fahr. (1582 degrees Cent.) and 2800 degrees Fahr. (1538 degrees Cent.). Aluminum is added to the ladle in amounts equivalent to 500 grams per ton, prior to pouring.

(7) *Recording and Duplicating of Data*

21. After the bars have cooled to room temperature, the films giving a photographic record of the temperature and shrinkage are developed, projected, and the readings recorded. As several heats are always run at each carbon content, the readings obtained from steels of the same carbon content are compared, averaged, and finally plotted as shown in Figs. 9 to 12, inclusive.

22. The curves have been reproduced three or more times and in each case, the agreement between the several trials has been very good. The data obtained, with a 0.14 per cent carbon steel, on two freely contracting bars and two bars restrained by the strong "*C*" spring are shown on Fig. 7. The two curves are the extremes since a third heat of 0.14 carbon steel gave results approximately midway between those curves shown.

23. A very complete study was made of the rate of cooling of the contraction bar. Thermocouples were inserted to the axis of the bar at the gate and near the end of the bar. The skin temperature of the bar also was studied. The data showed (Fig. 8) that at the end of 4 minutes the bar was cooling uniformly throughout. The maximum variation between the center and the ends of the bar was about 30 degrees Cent. (54 degrees Fahr.) at 2 minutes.

The skin never attained a temperature of more than 1400 degrees Cent. (2552 degrees Fahr.), showing that a solidified outer crust was formed immediately after pouring.

24. It was thought that perhaps the variations that existed in the manganese and silicon content in cast steel, might have some effect on the rate of contraction and the total contraction. To prove this point, molten ferromanganese was added to the ladle after one set of bars had been poured with the usual manganese content, and the remainder of the heat poured. The data showed that there was no difference either in the rate of contraction or in the total contraction, even though the manganese was increased from 0.70 to 1.09 per cent. The carbon and silicon content, of course, remained approximately the same during pouring.

25. The effect of silicon was determined in the same manner, with the carbon and manganese remaining constant. Although the silicon content was increased from 0.35 per cent to 0.60 per cent, the rate of contraction and the total amount of contraction were not changed.

26. The most serious criticism that can be made of this work is that stainless steel bolts were used in obtaining the amounts of contraction. This was done as stainless steel has high strength properties at high temperatures and would resist the tension stresses imposed by the heavy springs. The stainless steel bolts were also used on the freely contracting bars as similar conditions throughout were desired.

27. It is true that the coefficient of expansion of stainless steel is very high, being of the order of $0.17 \times 10^{-4}$ per degree Cent., and therefore is not especially adaptable for contraction studies, but a material of a low coefficient of expansion, such as quartz ($0.006 \times 10^{-4}$ per degree Cent.) and tungsten ($0.03 \times 10^{-4}$ per degree Cent., will fracture under the stress of hindred contraction.

28. A temperature study of the steel bolt showed that at $\frac{1}{8}$ in. away from the cast steel gripping the bolt, a temperature of 680 degrees Cent. (1256 degrees Fahr.) was reached in $\frac{1}{2}$ minute, and a maximum of 710 degrees Cent. (1310 degrees Fahr.) in 2 minutes. The gauge end of the bolt was at room temperature during this time, but slowly increased to a maximum of 70 degrees Cent. (158 degrees Fahr.) at 40 minutes. From these figures, it was thought that because of the high coefficient of expansion of the steel bolts, the curves would be slightly under the true theoretical values, though the starting points and the final end points should

not be affected, as the bolts at these times would be at room temperature.

29. To obtain an idea of the correction values, several experiments were carried on using quartz rods in the place of the steel bolts. The data obtained was not fully conclusive as the quartz fractured badly under the contracting steel. Tungsten rods were then used. The results obtained are shown in Fig. 6. It will be noticed that the maximum variation comes during the temperature interval of 1000 to 600 degrees Cent. (1832 to 1112 degs. Fahr.) which corresponds to a time interval of 10 to 40 minutes after pouring. The final room temperature readings are approximately the same.

30. These corrections, due to the expansion of the bolts, were not applied to the curves as given in the Figs. 9 to 12 inclusive, because they were of the same order of magnitude as the values

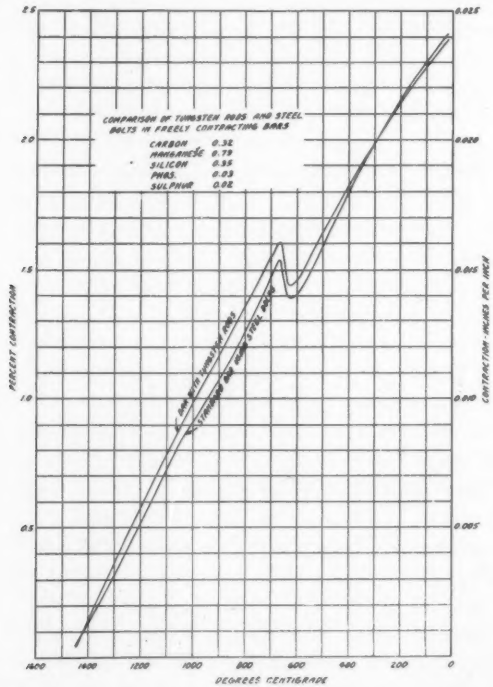



FIG. 6—COMPARISON OF TUNGSTEN RODS AND STEEL BOLTS IN FREELY CONTRACTING BARS.

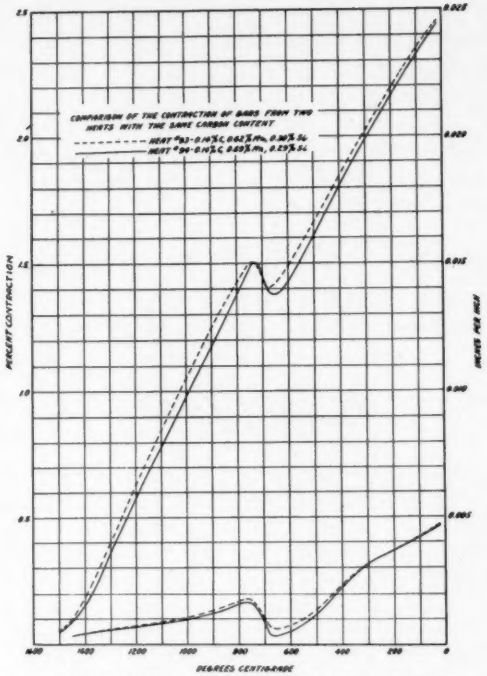

COMPARISON OF THE CONTRACTION OF BARS FROM TWO HEATS WITH THE SAME CARBON CONTENT
PERCENT CONTRACTION
INCHES PER INCH
DEGREES CENTIGRADE

Fig. 7—Two Heats with the Same Carbon Content.

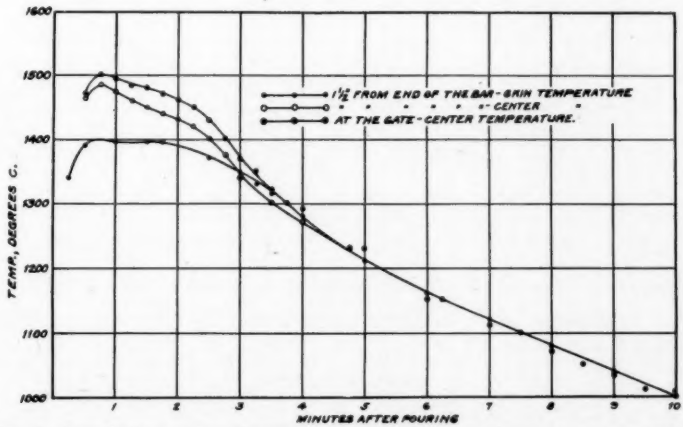



Fig. 8—Comparison of the Temperature at Various Positions in the Contraction Bar.

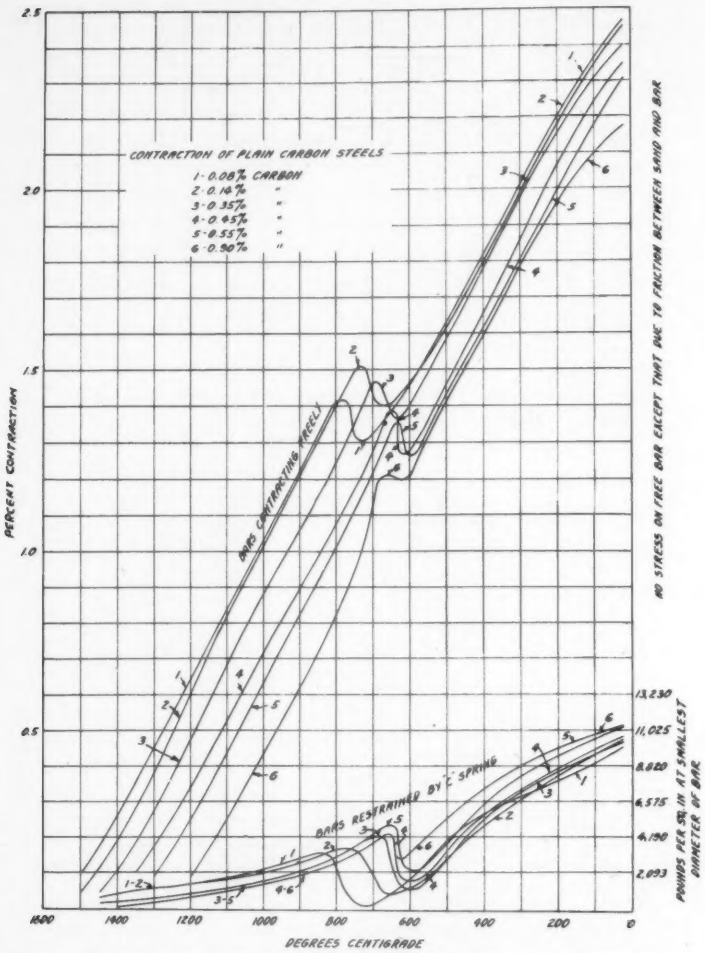



FIG. 9—CONTRACTION OF PLAIN CARBON STEELS (FREE AND "C" SPRING).

obtained in the duplication of data as is shown in Fig. 7, where the contraction of bars from two heats with the same carbon content is compared.

## DATA OBTAINED

### (1) *Freely Contracting Bars*

31. The data shown on the curves given in Figs. 9, 10 and 11

and in Tables 1 to 4, list the carbon contents of the steels used as 0.08, 0.14, 0.35, 0.45, 0.55 and 0.90 per cent. The manganese, silicon, phosphorus and sulphur contents were typical of those found in cast steels and were maintained within the following limits: manganese 0.55 to 0.80 per cent, silicon 0.25 to 0.40 per cent, phosphorus and sulphur less than 0.05 per cent.

32. The data obtained from freely contracting bars are given in Table 1 and shown graphically in Fig. 9.

33. It will be noted that the total contraction recorded decreases as the carbon content of the steel increases. This is also true of the amount of contraction taking place prior to reaching the critical point, with the exception of the data obtained with 0.08 per cent carbon. The amounts of contraction obtained after the steel has passed through the critical range are approximately equal, with the exception of the 0.08 per cent carbon steel which again appears to be out of line.

34. The graphical representation of the data (Fig. 9) shows that the curves are roughly parallel to each other throughout most of their length. The principal differences occur at the higher temperatures, for it appears that the carbon content influences the

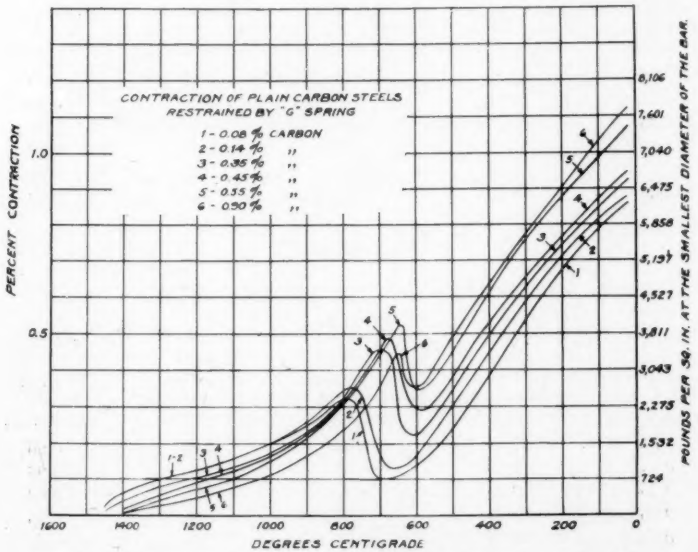



Fig. 10—Contraction of Plain Carbon Steel Restrained by "G" Spring.

rate of contraction markedly until the bars have contracted approximately 0.10 per cent. The rate of contraction at these higher temperatures decreases rapidly with an increase in carbon content. A portion of this lag in contraction can be explained by the lower solidifying temperature of the high carbon steels but as this is only

**Table 1**

DATA ON FREELY CONTRACTING CAST STEEL BARS

| Cast Steel—Per Cent Carbon | Per Cent Contraction Before Critical Range | Per Cent Expansion Passing Through Critical Range | Per Cent Contraction After Critical Range | Per Cent Total Contraction |
|---|---|---|---|---|
| 0.08 | 1.42 | 0.11 | 1.16 | 2.47 |
| 0.14 | 1.51 | 0.11 | 1.06 | 2.46 |
| 0.35 | 1.47 | 0.11 | 1.04 | 2.40 |
| 0.45 | 1.39 | 0.11 | 1.07 | 2.35 |
| 0.55 | 1.35 | 0.09 | 1.05 | 2.31 |
| 0.90 | 1.21 | 0.01 | 0.98 | 2.18 |

**Table 2**

DATA ON CAST STEEL BARS RESTRAINED BY THE STRONG "C" SPRING

| Cast Steel—Per Cent Carbon | Per Cent Contraction Before Critical Range | Per Cent Expansion Passing Through Critical Range | Per Cent Contraction After Critical Range | Per Cent Total Contraction |
|---|---|---|---|---|
| 0.08 | 0.15 | 0.14 | 0.45 | 0.46 |
| 0.14 | 0.17 | 0.13 | 0.44 | 0.48 |
| 0.35 | 0.20 | 0.15 | 0.42 | 0.47 |
| 0.45 | 0.21 | 0.14 | 0.41 | 0.48 |
| 0.55 | 0.24 | 0.13 | 0.40 | 0.51 |
| 0.90 | 0.20 | 0.06 | 0.38 | 0.52 |

**Table 3**

DATA ON CAST STEEL BARS RESTRAINED BY THE MEDIUM "G" SPRING

| Cast Steel—Per Cent Carbon | Per Cent Contraction Before Critical Range | Per Cent Expansion Passing Through Critical Range | Per Cent Contraction After Critical Range | Per Cent Total Contraction |
|---|---|---|---|---|
| 0.08 | 0.32 | 0.22 | 0.76 | 0.86 |
| 0.14 | 0.35 | 0.22 | 0.75 | 0.88 |
| 0.35 | 0.46 | 0.24 | 0.70 | 0.92 |
| 0.45 | 0.49 | 0.20 | 0.66 | 0.95 |
| 0.55 | 0.52 | 0.18 | 0.73 | 1.07 |
| 0.90 | 0.44 | 0.09 | 0.77 | 1.12 |

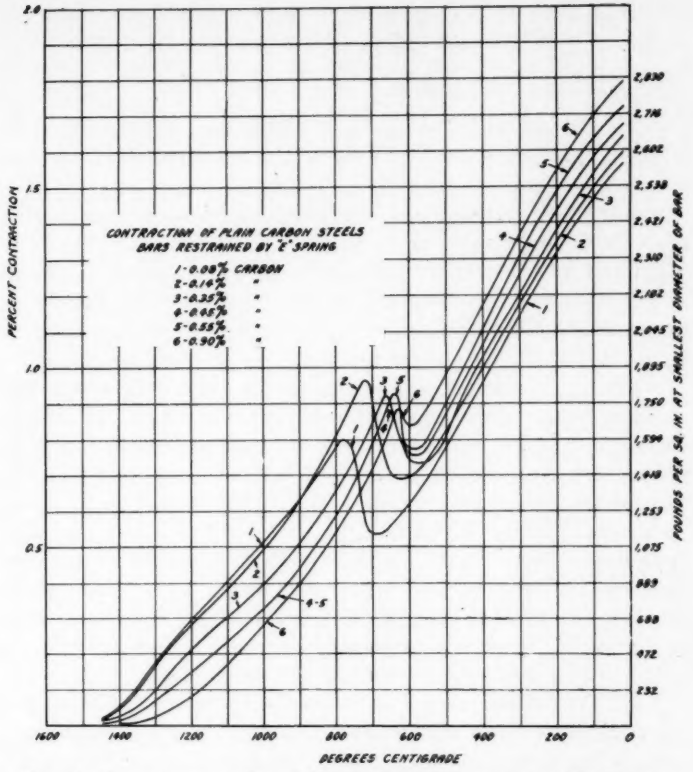



Fig. 11—Contraction of Plain Carbon Steel Restrained by "E" Spring.

**Table 4**

Data on Bars Restrained by the Light "E" Spring

| Cast Steel—Per Cent Carbon | Per Cent Contraction Before Critical Range | Per Cent Expansion Passing Through Critical Range | Per Cent Contraction After Critical Range | Per Cent Total Contraction |
|---|---|---|---|---|
| 0.08 | 0.80 | 0.27 | 1.03 | 1.56 |
| 0.14 | 0.96 | 0.27 | 0.90 | 1.59 |
| 0.35 | 0.92 | 0.18 | 0.90 | 1.64 |
| 0.45 | 0.90 | 0.13 | 0.90 | 1.67 |
| 0.55 | 0.92 | 0.15 | 0.95 | 1.72 |
| 0.90 | 0.88 | 0.04 | 0.95 | 1.79 |

a drop of about 50 degrees Cent. (90 degrees Fahr.) for the highest carbon content, it is not sufficient to account for the total lag.

(2) *Hindered Contraction*

35. In the study of hindered contraction, the bars were restrained from contracting by springs of three different sizes. These springs were used to cause tensions in the bars similar to those encountered by castings. The conditions presented by these springs may not be comparable in magnitude to the stresses actually encountered in commercial castings but they do give an indication of the effect of restraining contraction. The values in lbs. per sq. in., shown on the curves, were computed for the smallest diameter of the bar which has a cross-sectional area of 2 sq. ins.

36. A pronounced change in the contraction data was brought about by hindering the contraction of the bars (Figs. 9, 10 and 11). The data obtained (Tables 2, 3 and 4) can be divided into three parts, (1) the portions before the critical range, (2) passing through the critical range, and (3) after the critical range. Before the critical range was reached, the hindered bars contracted similarly to the freely contracting bars in that, at any given temperature, the amount of contraction is greater with lower carbon contents. In passing through the critical range, this was reversed so that at the lower temperatures the amount of contraction in the hindered bars was greater with higher carbon steels.

37. The temperatures at which the upper and lower critical points occur, were the same in both freely and hindered contracting bars except in two instances. The 0.08 and 0.14 per cent carbon steels, when restrained by the two stronger "*C*" and "*G*" springs, had higher upper critical points.

38. It is also to be noted that under the influence of the tension exerted by the springs, the amount of expansion resulting while passing through the critical is greater than recorded on a freely contracting bar. This increase in expansion is greater when the lightest spring is used.

39. The amount of contraction before and after the critical range, though different for each spring, is not greatly affected by the carbon content. The amount of expansion passing through the critical range decreases as the carbon content increases.

40. The percentage of the total contraction occurring before the critical range is reached decreases as the tension restraining the bar increases. In the freely contracting bar, about 60 per cent

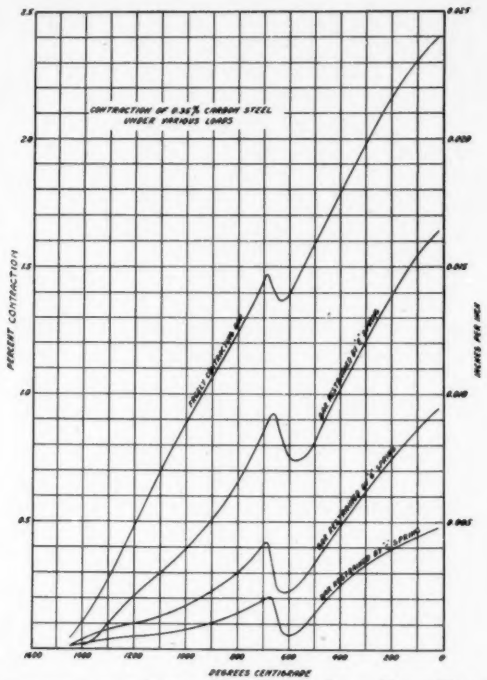



Fig. 12—Contraction of 0.35 Per Cent Carbon Steel Under Various Loads.

of the total contraction occurs before the critical range is reached. If the bar is hindered by the heavy "*C*" spring, this value is about 40 per cent, with the "*G*" spring about 45 per cent, and with the light "*E*" spring about 55 per cent.

41. The contraction of a 0.35 per cent carbon steel under various loads is shown on Fig. 12. The marked decrease in the amount of contraction caused by increasing the tension on the bar is to be noted.

(3) *Specific Volume of Carbon Steel*

42. From time to time, there arises an occasion to evaluate the amount of contraction that takes place during the solidification of cast steel from the liquid to the solid state. Recently, Tammann and Bandel[6] have reviewed the subject of the specific volume of steel and have pointed out the fact that there is quite a large discrepancy between the results of various works as to the change in

specific volume upon the melting of iron or steel. Values have ranged from 0.0061 cm.³/gr., as reported by Desch and Smith,[7] to 0.0019 cm.³/gr., obtained by Benedicks, Ericsson, and Ericson[6] including those results of 0.0037 cm.³/gr. obtained by Sauerwald and Widawski[8]. Tammann claims that the average, or .0039 cm.³/gr. is probably an excellent figure for iron.

43. The solidifying contraction value for a 0.35 per cent carbon steel would be somewhat of the same general nature, as the specific volume of both liquid steel and solid steel increases as the carbon is increased.

44. Benedicks, Ericsson and Ericson[5] have determined, by the communicating U-tube method, the specific volume of various carbon steels. Desch and Smith, and Sauerwald and Widawski have also made several determinations of the liquid specific volume of steels but, as their data are not nearly as complete as those exhibited by Benedicks and co-workers, it will not be considered at this time.

45. The data of Benedicks, Ericsson and Ericson are extrapolated to present the liquid contraction of a 0.35 per cent carbon steel as is shown by the line *AB* in Fig. 13. The curve *CD* is the contraction data as obtained on a freely-contracting, 0.35 per cent

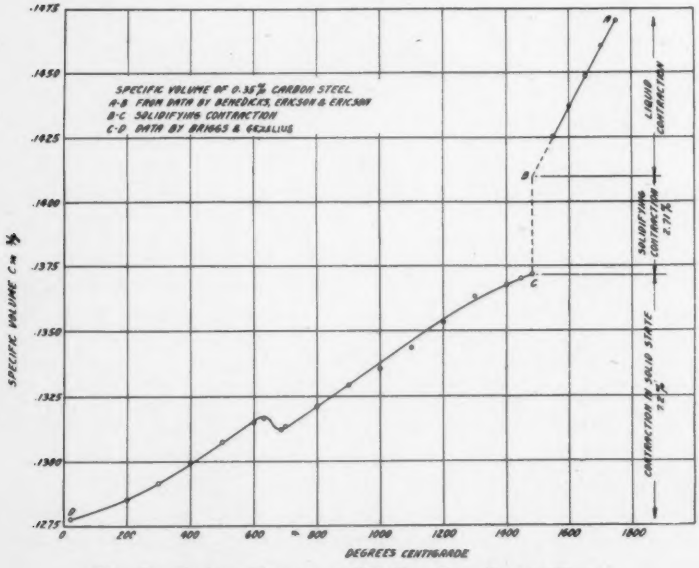



FIG. 13—SPECIFIC VOLUME OF 0.35 PER CENT CARBON STEEL.

carbon steel by the authors. The line *BC*, therefore, represents the amount of solidifying contraction, which in this case is 0.0039 cm.³/gr., and is in excellent agreement with the average as set forth by Tammann. Thus, a figure of 2.7 per cent is obtained for the solidifying contraction. This figure is somewhat lower than the figure of about 4.4 per cent as calculated by Honda and Endo[9]. There is need for further information along these lines and it is hoped that in the near future, further data will be obtained appertaining to the liquid specific volume and the solidifying contraction of cast steel.

## Discussion of the Practical Features as Exhibited by the Data

46. The amounts of total contraction obtained on the freely contracting bars are considerably higher than any previously recorded. The data obtained indicate that the contraction varies from 2.47 per cent for a 0.08 per cent carbon steel to 2.18 per cent for a 0.90 per cent carbon steel. These results, of course, have little practical application, for few commercial castings are able to contract freely.

47. The data obtained with the lightest "*E*" spring, probably represents more closely the stresses encountered by the average commercial casting as the total contraction recorded under this tension approximates the "patternmaker's shrinkage" of 3/16 in. per foot (1.56 per cent). The contraction recorded, using this spring, varied from 1.56 per cent with a 0.08 per cent carbon steel to 1.79 per cent with a 0.90 per cent carbon steel.

48. The data recorded with the medium "*G*" spring, probably approximates conditions existing in castings which, due to design or to unusually high mold resistance, are unable to contract a great deal.

49. The tensions exerted by the strong "*C*" spring, are probably greater than any encountered in commercial practice but the data are included to indicate how these unusually high stresses would effect contraction. It should be noted that with these very high stresses, the carbon content does not effect the amount of total contraction to any great extent. The amount of total contraction is very low for all carbon contents, being only 0.46 to 0.52 per cent.

50. An interesting point that is of great practical importance is brought out by the data obtained on the hindered contracting bars. In the case of the light "*E*" spring, where conditions are

similar to actual casting conditions, it will be noted that at 1300 degrees Cent. (2372 degrees Fahr.), the temperature range most susceptible to cracking, the 0.08 per cent carbon bar has contracted 0.18 per cent and has developed a stress of 425 lbs. per sq. in. on its smallest section, whereas the 0.90 per cent carbon steel has only contracted 0.002 per cent with a corresponding stress of about 50 lbs. per sq. in. When the 0.90 per cent carbon steel has contracted to the 0.18 per cent value exhibited by the 0.08 per cent carbon steel at 1300 degrees Cent. (2372 degrees Fahr.), the temperature is 1090 degrees Cent. (1994 degrees Fahr.).

51. This effect is even more noticeable in the cases of the bars restrained by the strong "*C*" spring. In this case, the 0.14 per cent carbon steel at 1300 degrees Cent. (2372 degrees Fahr.) has contracted 0.006 per cent, which results in a stress of 1200 lbs. per sq. in. At the same temperature, the 0.35 per cent carbon steel has only contracted 0.003 per cent and thus has to resist only a stress of 600 lbs. per sq. in. The 0.35 per cent carbon steel cools to a temperature of 1070 degrees Cent. (1958 degrees Fahr.) before it has to resist the same tension as the 0.14 per cent carbon steel does at 1300 degrees Cent. (2372 degrees Fahr.).

52. There has been considerable discussion as to the relative strengths of cast steels at temperatures near the melting point. These data point out the fact that the rate of contraction as well as the strength of the steel may influence the formation of hot tears in steel castings. The examples given previously show that, if the strengths of the 0.14 and 0.35 per cent carbon steels were identical at a given temperature, the danger of the formation of hot tears would be greater in the 0.14 carbon steel as the rate of contraction, and therefore the rate of stress increase, is greater. These relative rates of contraction apply under all conditions of hindered contraction down to the critical range.

53. One practical use of data of this type is the determination of the amount of stress that any particular casting has withstood. It should be possible by measuring the completed casting and the pattern to determine the amount of contraction and from this the tension the casting has encountered.

## SUMMARY

54. The authors offer the following summary as a conclusion to this paper:

(1) The total amount of free contraction of cast carbon

steel decreases as the carbon content of the steel increases. The contraction varies from 2.47 per cent for 0.08 carbon steel to 2.18 per cent for 0.90 carbon steel.

(2) The amounts of contraction, of the freely contracting bar, taking place prior to reaching the critical range, decreases as the carbon content of the steel increases.

(3) The amounts of contraction obtained after the freely contracting bars have passed through the critical range are approximately equal.

(4) In the case of the freely contracting and the lightly hindered contracting bars, the carbon content influences the rate of contraction markedly until the bars have contracted approximately 0.10 per cent.

(5) Hindered bars contract similarly to the freely contracting bars in that, at any temperature prior to the critical range, the amount of contraction is greater with decreasing carbon contents.

(6) The total amounts of hindered contraction increase as the carbon content increases.

(7) The percentage of the total contraction occurring before the critical range is reached decreases as the tension restraining the bar increases.

(8) The hindered contraction data, obtained with the lightest spring, represents approximately the stresses encountered by the average commercial casting as the total contraction under this tension approximates the "patternmaker's shrinkage" of 3/16 in. per foot.

(9) Slight variations from the normal manganese or silicon content of cast carbon steel do not result in measurable differences in the rate or total amount of free or hindered contraction.

(10) The rate of contraction, as well as the strength of the steel, may influence the formation of hot tears in steel castings.

(11) The contraction taking place upon the solidification of cast steel, as approximated from the present available data, is 2.7 per cent.

## Acknowledgment

55. The authors wish to thank various members of the Naval Research Laboratory for their ready cooperation in the research

problem; Dr. R. H. Canfield for his good counsel and valuable criticisms, James Darby and Roy Donaldson for their aid in the test procedures, and Louis Singer for chemical analyses.

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## DISCUSSION

C. E. SIMS[1], (*Submitted in Written Form*): The authors are to be commended for doing a difficult job so well. Fundamental data on the high temperature characteristics of steel are few, and many are uncertain because of difficulties involved. Ingenuity has been shown here in overcoming the problems in technique and figures have been checked to the extent that they seem certain to be reasonably accurate.

There seems to be one significant point in connection with the data on restricted contraction which has not been emphasized. The bars that were restricted in their contraction were obviously stretched. These bars could contract only by stressing the spring and the load on a bar was always equal to that of the spring. They would all have contracted more if unrestricted. A bar cannot maintain a stress higher than its yield strength at the moment. Therefore, we must conclude that the stress set up in a restricted bar represents its yield strength at that temperature.

Thus, it is shown in paragraph 50 that at 1300 degrees Cent. (2372 degrees Fahr.) an 0.08 per cent carbon steel has about 8½ times the yield strength of a 0.90 per cent carbon steel. Also, at the same temperature (see paragraph 51), a 0.14 per cent carbon steel has twice the yield strength of an 0.35 per cent carbon steel.

The bars in contracting could only develop a stress equal to their yield point. This has nothing to do with the ultimate strength of the bar; probably at such temperatures, it would be very difficult to reach the ultimate strength. The flow might be so great and so continuous that we could not get sufficient distortion to reach the ultimate strength.

In view of the wide variation in results obtained for solidifying contraction, I wish to put this open question before the authors and this meeting. Is there any reason to believe that there is a variation in the liquid contraction of individual heats of similar compositions? It is the firm belief of many foundrymen that there is.

F. A. MELMOTH[2], (*Submitted in Written Form*): Our experience of previous work by these two authors, submitted to the 1933 Convention, would lead us to expect information of both academic value and practical application, and the present paper is no disappointment in these respects.

Work of the type now undertaken has long been seriously needed in connection with the manufacture of steel castings, but very few steel foundries exist either as a whole or part of large enough organizations to be able satisfactorily to tackle the questions as they should be tackled. The results of these studies, therefore, are of increased importance and value, as they offer for the practical steel founder examples of scientific proof and demonstration of practically observed facts.

It has been my experience, and that of many of my colleagues engaged in similar work, that complicated castings containing an abundance of cores, in other words, of a type most liable to produce heavy stresses in the cooling casting, due to mold and core obstructions to normal con-

[1] American Steel Foundries, East Chicago, Ind.
[2] Detroit Steel Casting Co., Detroit.

traction, are infinitely less liable to hot-cracking when produced in a medium carbon steel. It might logically be said that going to a very high carbon would still further reduce the jeopardy associated with the production of this class of casting, but, as we know, other economic reasons—machining, etc., and the meeting of certain physical test specifications—exert a controlling influence on the degree to which one can take advantage of the improving effect of higher carbon content. This brings to mind some very interesting remarks made by Mr. McKinney during discussion last year, regarding the anomalous position of the steel founder, in that he was compelled, in order to meet stringent physical requirements, more particularly as regards ductility, to use types of material not best adapted to produce safely the work he has in hand.

I was surprised to note that the influence of increased manganese content apparently had little or no bearing upon the degree of contraction, carbon content being almost completely the controlling factor. We have been in the habit of raising both carbon and manganese for the type of casting which I previously mentioned, but in view of the precise results now recorded it would certainly appear that we have been allocating to the manganese content, incorrectly, a portion of the beneficial effect due to higher carbon content.

I believe this paper to be a really serious contribution to the practical steel founder's contraction problem, and I sincerely trust that the work will be carried still further by these authors, and that this Association will be given the benefit of further results as they arise.

JOHN HOWE HALL[3]: I do not need to say that I consider this paper a most valuable contribution to our all too scanty knowledge of some of the things that we ought to know. It is very surprising to me, that as stated in paragraph 9 that in that little end piece with a very heavy chill inside, the chilling effect died out in a half inch, as shown by the thermocouple.

It is very interesting to see this confirmation of the idea that has been before us so long, that carbon has a very profound effect on the amount of contraction and on the amount of tearing in steel castings. Probably all metallurgists who are responsible for meeting physical properties in castings have had to fight with foundrymen to keep them from raising the carbon in the belief that higher carbon steel is least prone to tear. The data here published, unless I misread it, confirm that idea. Mr. Melmoth called attention to the conclusion in paragraph 24 that high manganese, up to 1.09 per cent anyway, has very little to do with the formation of hot tears or with contraction. That does not agree with the experience of most steel founders. Steel with about 25 per cent carbon and about 1.25 per cent manganese (with various modifications) which has become so popular of late, has everywhere had the name of being very prone to tearing in the molds. I have been told that by enough foundrymen, whose opinions I value very highly, to believe that it is so, and my own outfit has railed at me more than once for ever having assisted in the birth of high manganese steel, because, as they expressed it, it was a very mean steel in the molds.

[3] Taylor Wharton Iron and Steel Co., High Bridge, N. J.

It is not clear to me, whether these bars, when the spring is released, stay right where they are or spring in a little.

MR. GEZELIUS: They stay where they are.

MR. HALL: In other words, they are what Howe called "virtually expended", in a phrase he coined when he was writing about the mechanism of the formation of shrinkage cavities in ingots. By the way, I cannot avoid getting back to that subject again. When Howe wrote his papers on ingot pouring practice, he proved that whether steel expands, stands still or contracts in cooling, there will always be a cavity at the top of a steel ingot.

At the risk of seeming out of order or of not knowing what I am talking about, I want to raise a question with regard to pouring temperatures. Mr. Sims touched on that in his discussion when he asked whether there is a difference in the actual contraction between two steels of similar analysis.

I should like to raise the question, which I hope Messrs. Briggs and Gezelius will give attention to in their researches, whether there is not a difference in the contraction of two castings from the same ladle of steel poured at different temperatures? It is always a little dangerous to draw sweeping conclusions in the early stages of such an extensive research as Messrs. Briggs and Gezelius have started, and at least in certain steels the conclusions that it is good practice to pour hot, is open to serious challenge.

As I read Fig. 13, the only difference that would occur, as far as the data show, due to pouring at higher and higher temperatures, would be that the line *A B* showing contraction in the fluid state would be prolonged upward to the right. That is, if you poured several successive tests from the same ladle of steel at successively lower temperatures, you would simply have a shorter and shorter *A B*. Then at *B*, the freezing point, you would get contraction in solidifying, equal to *B C*. From there down, you would get the same amount of contraction in the solid, whatever the pouring temperature. I question whether that is yet proved, and I think it is also questionable how advantageous it may be to pour steel too hot.

We have been making some rather crude experiments, and I know other foundries that have been doing similar work, to prove whether heats of austenitic manganese steel made from different kinds of material, did or did not have a varying tendency to crack or hot tear.

We rammed up a number of test pieces in the shape of an I-beam using very hard dry sand so as to eliminate as far as we could, the variable of sand compressibility. Sets of those bars 3, 5, 7, 9 in. long and so on, were poured from various ladles of steel. Some of the sets were poured from very hot metal, some from colder metal.

If it be true that the only difference you would get from hot pouring would be a longer line *A B*, it is hard to explain the fact that the one dominating factor in the results secured from these bars was pouring temperature. If we poured "cold", both the 3 and the 12-in. bars molded in that very hard dry sand would hold together, and if we poured very hot, everything but the very shortest bars would tear, and tear badly.

That is due in part to the fact that some of the high alloy steels, when poured very hot, have an entirely different crystal structure from what they have if they are poured cold. When poured hot, they have a columnar grain which is exceedingly weak and apparently much more likely to rupture than the fine grain produced when they are poured "cold". It may be that the only difference was in the crystal structure, but it is possible that variations in pouring temparatures affect the amount of solid contraction below the freezing point. We did not find much difference between heats of steel of almost identical analysis made from different materials, but we found an enormous difference due to pouring temperature.

CHAIRMAN BULL: It is my understanding of the paper, that the authors do not presume to say that pouring temperature is no factor. It is to be hoped they will, however, be able to make some equally accurate tests and throw light on that particular matter. It occurs to me to mention this possibility in connection with Mr. Hall's discussion of the effect of manganese, which is touched on in this paper.

There are some foundrymen who believe that steel containing, say, 1.00 to 1.25 per cent manganese has a better fluid life than steel containing around 0.75 per cent manganese. I am not sure that that is true, but if it is true, then the apparent effect of manganese on hot tears may be superficial rather than real, simply because the steel foundryman who makes a considerable quantity of thin sections must get his steel hot enough at the start to have sufficient fluid life at the tail end of it. He may have to open his ladle a great many times. So when you consider that in these experiments, the steels were all poured at substantially the same temperature, the conclusion drawn by the authors may be absolutely correct. However, a condition we have to meet in the foundry is to get fluid life, and if the 1.00 per cent manganese steel does have a greater fluid life than the 0.75 per cent manganese, that means to start with that we have to get a higher temperature at the top, with the strong probability that in that state of high temperature the steel would have a greater tendency to be red short.

P. E. MCKINNEY[4]: I did not get time to prepare a written discussion although I have read the paper with considerable interest. The authors stated that it was a high-brow paper, possibly inferring that the subject matter of this paper might not be of particular interest to practical foundrymen. I can take another view of that, and state that I feel that this paper, as well as the previous one which it supplements, contains some of the most valuable data that can be most practically applied to steel foundry practice as we have it confronting us today. It is the engineering data that every steel foundrymen confronted with serious problems needs.

The data on the different carbon contents is extremely interesting. It naturally leads us to feeling that we should speculate much further on the influence of the composition on contraction characteristics of solidifying steel.

I cannot agree that the conclusions of the authors and the statements

[4] Bethlehem Steel Co., Bethlehem, Pa.

Mr. Melmoth made regarding the influence of carbon and manganese are at all inconsistent, because I have in mind that the authors, in discussing the influence of compositions, have stated that material of the same strength would indicate the superiority of one carbon content to the other. I feel that they cannot entirely explain hot tears in this discussion without taking into consideration the possible strength of the material at these temperatures; not only the strength in the higher critical range where we feel hot tears occur, but also that in the secondary brittle range which occurs well below the critical point.

I feel that, as a supplement to this work, a study should be made of some of the alloy steels containing molybdenum, nickel, and other elements which very seriously affect the critical points in an attempt to correlate those measurements of contraction from the liquid to the solid by this very excellent method with dilatometer measurement of the same characteristic on a previously solidified bar. This should give us very valuable additional information.

I feel that the series of papers that have been presented by the Naval Research Laboratories are of extreme value. It is a type of information that a public institution of that kind can furnish that is of value to the entire industry.

MR. SIMS: The work we have done and the observations made in the foundry check very well with many of the assertions in the paper. For instance, the relation between carbon content and hot tears. It has been often observed in the foundry that the high carbon metal does tear less than the lower carbon metal, but contrary to some of the statements made here, we find that the medium manganese steel tears less than the carbon steel. We do not find any need to vary our shrinkage allowance on the pattern, which would be in line with the statement that manganese did not affect the restricted contraction, but we do have less trouble with hot tears and we found that some other alloys have a similar effect.

MR. BRIGGS: There are a few points brought up during the discussion which we would like to call to your attention. Mr. Hall may be surprised regarding the end chilling effect of the bolt, but it would not have been so surprising if it had taken him six months to develop the contraction bar, as it did us. In regard to the amount of liquid contraction, we have a method, we believe, that will produce the correct results, and we are going to proceed along that line shortly.

In regard to contraction and hot tears, it is not our purpose to bring before you the point that contraction is not wholly responsible for hot tears. We wish to point out that contraction characteristics as well as strength properties must be borne in mind when the hot tear problem is considered. Heretofore, everyone has talked merely of the steels having different strength properties at high temperatures and have said nothing about the rate of their contraction. The research data shows that carbon steels have different rates of contraction and these rates may influence hot tear formation. There is indeed a need for further information concerning the strength of cast steels at the very high temperatures, and it is along that line we are now proceeding.

We should like to thank Messrs. Melmoth, Sims, Hall, Batty, Mc-

Kinney and Chairman Bull, for their encouraging remarks; it is indeed very considerate of them to express their opinions of the value of the Navy's research program on steel castings. It has been our aim to make the research as practical as possible as well as to bring forward needed theoretical values.

MR. GEZELIUS: Mr. McKinney pointed out the fact that we should really carry on our experiments on a larger scale, that alloys of different compositions should be taken into consideration. The data we presented in this paper on manganese and silicon were not presented as studies of alloy steels. It was impossible to maintain a uniform manganese or silicon content throughout a series of experiments. Therefore, we studied only the ranges that would be comparable to those we had in our experiments to show that the effect was not appreciable. In the near future, we intend to go into alloy steels on a larger scale, and at this time we are very much interested in finding out in what alloys foundrymen are interested. If any of you have a particular alloy that you would like to have us study, we will be only too glad to attempt it.

CHAIRMAN BULL: I would like to say, commenting on these last remarks, that these gentlemen carrying on this investigation for the Navy Department are certainly doing a very constructive job and one that is very much appreciated by the steel castings industry. The statement that your comments on particular steels are invited should prompt quite a number of letters addressed to Messrs. Briggs or Gezelius. I hope it may be possible for them, before very long, to present to this Association some information that may be confirmatory regarding the effect of pouring temperature on hot tears. Certainly the work that has been reported today confirms the impression that unquestionably exists in the steel casting industry in respect to the influence of carbon content.

# Symposium—Testing Cast Iron

## Test Bars

By R. S. MacPherran*, Milwaukee, Wis.

**Abstract**

*The author presents a brief review of the status of test bars for cast iron. He reviews the tests that are being carried out to determine the relation of the test bar properties to casting properties and gives the purpose of tentative specifications that have been drawn up for transverse and tensile tests. He also corrects a misunderstanding that exists as to the purpose of the specifications and reports the progress that is being made on impact testing.*

1. Prior to 1932, cast iron standard test bars were 1.20 and 1.25 ins. in diameter and the bars as tested represented the quality of "the iron in the ladle." The standard bars did not attempt to show any relation to the strength of the iron in the casting.

### Relations of Test Bars to Properties of Casting

2. In 1932, A.S.T.M. Committee A-3 proposed a set of specifications[1] which, when finally revised and adopted, will represent the strength of the iron in the casting itself. To secure test bars, the results from which will represent the properties of the iron in the castings, bars of various diameters are being investigated; first, to determine the diameter of a bar which will have properties like the casting itself; and second, to correlate transverse and tensile strength values. Thus far, 7/8, 1.20 and 2.0 in. diameter bars are being investigated. Certain tentative specifications have been drawn up specifying these bars to determine their inter-relationship and also their value as compared with specimens taken from castings of the same thickness. It may be necessary, before final adoption of these specifications, to introduce bars thicker and thinner than those already proposed.

* Allis-Chalmers Mfg. Co., and Chairman of A.S.T.M. Sub-Committee XIV, of Committee A-3, on Correlation of Test Bar and Casting.

[1] These specifications are now in tentative form and are designated A.S.T.M. Spec. A48-32T.

Note: This is one of the papers presented at a Joint Meeting of the American Society for Testing Materials and the A.F.A., held in connection with the 1934 convention of the A.F.A.

### AN IMPORTANT PURPOSE OF SPECIFICATIONS

3. The purpose of the specifications being developed is to allow the engineer to specify an iron of a certain grade or number; the specimen cast from which will, when tested, show approximately the same strength as a specimen taken from the casting with which he wishes to compare them. Experiments made since the adoption of these tentative specifications, have shown that the sections of castings to be represented by the designated size bars must be thinner than those listed. For example, a 2-in. diameter round test bar will cool faster than a large casting of 2-in. wall section and the test bar naturally will show a greater strength.

4. Some German investigators report that up to a wall thickness of 1.18 in., a plate is properly represented by a round test bar whose diameter is equal to twice the thickness of the plate. This would mean that our 1.20-in. test bar, when cast in a separate mold, would only represent sections in a casting of fair size of perhaps $\frac{5}{8}$ to $\frac{3}{4}$ in. and that, to properly represent large castings of 2-in. thickness, it will be necessary to use a much larger diameter bar than our 2-in. test bar. This idea was forecast in J. W. Bolton's work on volume-surface ratio.

### MISUNDERSTANDING OF SPECIFICATIONS

5. There has been some misunderstanding of the specifications as printed. Some have assumed that castings meeting requirements for class 20, for example, would be made with one kind of iron only and that the same material would show the same results in the $\frac{7}{8}$, 1.20 and 2.0-in. diameter bars. That is not the intention of these specifications. The figures given under each bar size are for that bar only and are applicable to no other sized bar. A specification for a casting with controlling section of $\frac{7}{8}$ in. may be met by test results of a bar 0.875 in. in diameter under class 30 iron. This will show transverse load of 1200 lbs., and 30,000 lbs. per sq. in. tensile strength, but a 2-in. diameter bar made from the same iron will not show 30,000 lbs. per sq in. tensile strength.

### TRANSVERSE TESTS

6. Since drawing up these specifications, the committee has become more inclined to emphasize the importance of transverse tests with deflection curves and it feels that information given from these tests is as necessary as that given by the tensile test. Further developments along this line may be expected.

### Impact Tests

7. Impact tests also are being made and it is hoped that in the near future, some standard test will be developed which will show the comparative resistance of cast irons to suddenly-applied loads. Whether development will be in the shape of a single impact or one of repeated or increasing impacts, is still uncertain. The Caterpillar Tractor Co., Peoria, Ill., for example, is now working on a modified Charpy impact test using a bar of over 1-in. diameter resting on supports 6 ins. apart. We have been experimenting with a somewhat similar bar and are also trying the effect of increasing impact load and repeated impact.

8. At present the committee is in position to report progress only. From our own tests, however, it would seem that as the grades of iron become stronger or as the tensile strength increases, the impact values do not increase in the same ratio. This is somewhat in line with results obtained on the transverse test where a similar feature is often noted. For example, a high steel or high test iron mixture shows a much greater increase in tensile strength over the ordinary grades with not nearly as much change or improvement in its impact value. Impact test results must be studied by themselves for there is no definite correlation with tensile test results.

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## DISCUSSION

F. G. Tatnall[1]: The torsion impact test developed by the Carpenter Steel Company, determines impact in the higher hardness ranges where Izod and Charpy leave off. The curve of torsional impact toughness plotted against drawing temperature (Fig. 1 of this discussion), compares the torsion impact curve with the Izod impact curve and the Rockwell hardness curve. Other forms of impact on hard and brittle materials have not seemed to indicate the true impact resistance, probably on account of variable stress concentration due to the character of the specimen and the method of load application. In the torsion impact test, the shock is distributed over the full area of the specimen, small differences in toughness are shown readily and values are reproducible. Fig. 2 of this discussion, shows the reproducibility of results.

The test has been described in detail by Luerssen and Greene in *Proceedings*, American Society for Testing Materials, vol. 33, Part II, 1933. The metallurgical aspects of the subject, in conjunction with the studies of three tool steels, one of brittle timbre, one of tough timbre and a heading die steel, were discussed in considerable detail at the 1933 con-

[1] Baldwin-Southwark Corp., Philadelphia, Pa.

vention of the American Society for Steel Treating in Detroit by the same authors, whose paper is published in the 1933 *Proceedings* of that Society.

Little work has been done with this test in connection with cast iron, probably because it has not been brought to the attention of makers and

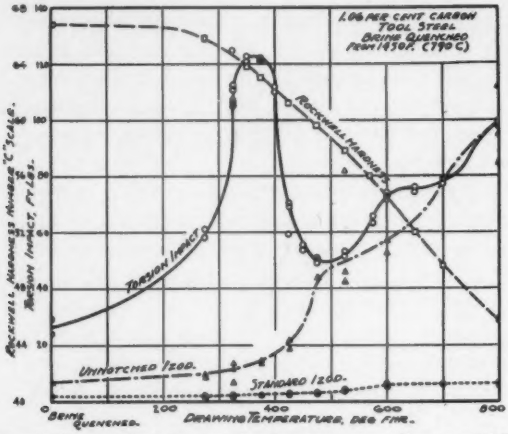


FIG. 1—TORSION IMPACT RESULTS IN COMPARISON WITH IZOD ON 1.06 PER CENT CARBON TOOL STEEL.

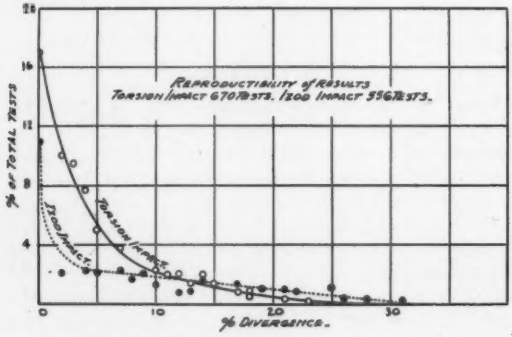


FIG. 2—REPRODUCIBILITY OF RESULTS.

users of cast iron. However, since cast iron is classified as hard and brittle, it falls into the field of the torsion impact test at a point where the maximum usefulness of the test resides.

Although this test began as a study of tool steels, it has been extended in interesting ways. Torsion impact has been used for shock tests not only of cast iron but of case hardened steels and hard and

brittle materials of many kinds other than ferrous, such as glass and ceramics. It has been used as a shock test for materials used in torsion, such as axles and shafts and finally as a test for machinability, wherein the similarity between the impact shear of the machining operation and the impact shear of the test gives rise to a measure of the property. Furthermore, the highly sensitive relation between heat treatment and toughness permits the desired machining properties to be picked from the curve and the heat treatment to obtain these properties determined. It has been used as a very sensitive test of surface corrosion, since the outside fibres of the material develop maximum stresses and are most affected by submicroscopic pitting.

F. F. VAUGHN[3]: The Caterpillar Tractor Company has done considerable work on impact testing of cast iron during the past four years.

At the start, we decided to use a type of test specimen of the same diameter as the arbitration test bar, *i. e.* 1.2-in. diameter, which would permit us to use the pieces of the arbitration bars remaining after the transverse tests were completed for this purpose. A pendulum type impact testing machine of 120 ft.-lbs. capacity was used for making the tests with the test specimens placed on anvil supports spaced 6 in. apart.

During approximately the first six months, specimens were tested with the surface "as cast," and, although variations in results between different bars cast from the same ladle of iron were not very great, it was realized that more uniform results could be obtained if test specimens with a machined surface were used. Since pieces of the test specimens were to be used subsequently for tension test specimens, we were restricted in machining the impact specimen to the 1.125-in. diameter of the tension test specimen.

Accordingly, we adopted 1.125 in. as the diameter and, since that time, all impact specimens have been ground in a centerless grinder to that dimension. This ground specimen gives more uniform results of approximately the same value as the "as cast" specimens. Other advantages of using a ground specimen are, easy detection of casting defects, thereby permitting the shifting of the specimens on the supporting anvils in such a manner as to avoid striking them with the test machine pendulum, and facilitation of subsequent machining operations in the preparation of the tension test specimens.

In verification of the statement of Mr. MacPherran in his paper that the tensile strength is no indication of the impact value, I can quote from our experience the following results: On 135 sets of bars from the same number of ladles of one type of alloy iron, the average impact value was 80 ft.-lbs., with an average tensile strength of 57,675 lbs. per sq. in. During the same period of time, on bars from a large number of ladles of the same base iron but with a different alloy content, the average impact value was 36.8 ft.-lbs. with an average tensile strength of 52,400 lbs. per sq. in. This also answers, in general, the question asked some time ago by Mr. MacPherran as to whether or not we noticed an increase in impact value proportional to the increase in tensile strength in different grades of high strength iron.

[3] Metallurgical Laboratory Supervisor, Caterpillar Tractor Co., Peoria, Ill.

We have noted in our tests that the impact value is influenced to a greater extent by the microstructure of the matrix than by the size or distribution of the graphite particles. We have had specimens with fairly coarse graphite that failed to break at 120 ft.-lbs. and specimens with comparatively fine graphite that broke at 40 ft. lbs. The type of microstructure we find conducive to high impact values in combination with high tensile strength, is readily detected by microscopic examination, and has been defined as acicular.

MR. MACPHERRAN: Has Mr. Vaughn ever tried the heat treatment of bars? If so, what effect has it on impact value?

MR. VAUGHN: Several test specimens of different types of grades of iron, when quenched in oil and drawn to hardness Rockwell "C" 45 to 50, showed approximately the same impact value as before heat treatment, although results were less uniform. Test results covering a range of draw temperatures are not available at this time.

CHAIRMAN J. T. MACKENZIE[3]: In connection with impact tests, it is probably a great convenience to use a single blow impact test, but there is nothing to be gained from it that cannot be secured from a transverse test. The repeated blow impact test, which we will call the drop test, does give you some information which is rather difficult to read out of the transverse test, in that it shows the degree of set, or plastic deformation under load. The single blow machine does not make the break occur in a different manner from the static test, so no great difference between such a test and a transverse test would be expected.

There is much more wasted energy in an impact test than in a transverse test because, in the transverse test, the actual deformation of the bar, if you have an accurate instrument, and the actual load on the specimen are read, whereas in the impact test of the pendulum type, the loss of energy of the pendulum is read, and this loss of energy consists, not only in the energy of rupture of the bar, but also the elastic deformation both in the supports, in the bar at the supports, and in the top of the bar where it is struck by the pendulum. If the ft.-lbs. used in the transverse and the ft.-lbs. used in the impact test are plotted, it will be found that more energy always is used in the impact test.

We have been experimenting at our plant with the new type bar developed by the U. S. Bureau of Standards, and this bar seems to render machining unnecessary; in fact, Mr. Saeger's paper on test bars presented last year before the A.F.A., gave the first results I ever saw in which machined test bars broke lower than unmachined test bars. At the Bureau, they have succeeded in making beautiful surfaces on the bars. I would like to ask Mr. Saeger to describe his method roughly and tell us something of the tests he is running at the Bureau of Standards.

C. M. SAEGER JR.[4]: The Committees on Cast Iron of both the American Society for Testing Materials and the American Foundrymen's Association have expressed the desirability of the Bureau extending its investigation of "Properties of Gray Cast Iron as Affected by Casting

[3] American Cast Iron Pipe Co., Birmingham, Ala.
[4] National Bureau of Standards, Washington, D. C.

Conditions." The results of this investigation were presented* to this Association in 1933. The report dealt with a method developed at the National Bureau of Standards for preparing transverse test bars in dry sand molds. The Committees on Cast Iron desire that we investigate the possibilities of the application of this method for the preparation of transverse strength bars in green sand molds.

Investigation has been started along this line following very closely the method used in our previous investigation of transverse strength bars prepared in dry sand. The type of mold and method employed in the dry sand operation was that of casting bars of the following diameter, 2.2, 1.5, 1.2, and 0.75 ins., 23 ins. long, in pairs. These bars are molded in a vertical position, being arranged so as to minimize the heating effect of the large diameter bars on the small ones. A runner ring at the base of the bars fitted with a tapered down-gate restricted at its base to one-in. diameter controlled the rate at which the metal filled the mold. A grade of Lumberton sand tempered to approximately 7 per cent moisture was used for molding.

The mold cavities were blackened with a mixture of Ceylon graphite, clay, molasses and water. The blackening mixture was poured into the mold cavity which was plugged at the bottom to permit the filling of the entire cavity; when filled, the plug was removed and the excess blacking material permitted to flow out of the mold. The mold was then placed in an oven and dried at a temperature of 200 degrees Cent. (392 degrees Fahr.) for a period of 7 hours and then allowed to cool. The cope of the mold containing the pouring basin was molded in green sand and the ends of the bars were vented through the cope. The mold was placed in front of the furnace for direct pouring. The pouring temperature in all cases being 150 degrees Cent. (270 degrees Fahr.) above the liquidus temperature of the pig iron used.

In the present investigation, the transverse test bars are made in a molding mixture of 8 parts Lumberton sand to one part of sea coal. The mold cavities are faced with a carbonaceous substance commercially known as "Shake-On."

The transverse strength bars made according to the method just described have been found to be very satisfactory from the standpoint that there is no sand burnt on to the bars and the surfaces are free from any defects. The pouring temperature used in all of our tests is 150 degrees Cent. (270 degrees Fahr.) above the liquid temperature of the stock pig iron.

The results of transverse strength tests on duplicate bars of 2.2-in. diameter varied only 3 per cent in breaking loads. The 1.2-in. diameter bars varied 2 per cent, and the 0.75-in. diameter bars, 3 per cent. We consider these results to be quite satisfactory. It is planned in continuing our study on the preparation of transverse bars, to prepare bars made according to the American Society for Testing Materials Specification A48-32T and compare the results obtained by these methods with the results obtained on bars made according to the Bureau's method.

* Saeger, C. M. Jr., and Ash, E. J., *"Properties of Gray Cast Iron as Affected by Casting Conditions,"* TRANS. A.F.A., v. 41, pp. 449-468 (1933).

CHAIRMAN MACKENZIE: We have some data for the committee on the type of casting that Mr. Saeger is talking about and we have gone further and investigated the 0.6-in. diameter test bar suggested by Mr. Bolton as a possible bar for the light castings industry.

We also made a plate type bar. The plate is cast in a mold roughly 3x12 ins. The plates are placed in a milling machine and cut into two, ½-in. strips. The cast iron pipe industry uses a strip ½-in. thick and the width of the pipe wall as a test acceptance specimen. This bar is broken on 10-in. supports with the load set at the one-third point; that is, 3 1/3-ins. apart and 3 1/3-ins. from each end. That method has the advantage of testing the whole 3 1/3-ins., since the stress is theoretically the same across the middle third of the test piece instead of having a theoretical maximum stress immediately under the support, as in the conventional one point loading.

We tested those bars both with single point loading and with the 3 1/3 point loading. We made two sizes of plates; one ¼-in. thick and one, 0.4-in. thick. We will make the results available to the committee.

On the strips, we are in a position to use the modulus of rupture instead of breaking load because the modulus of rupture on the strips varies extremely rapidly, as the thickness. If the modulus of rupture is adopted by the A.S.T.M., there will be no point in making a standard test bar. If you are making a casting, with an 8-in. section, you may make an 8-in. diameter test bar and report the modulus of rupture. As it is now, breaking load on a 2-in. diameter bar is reported. If a 4-in. diameter bar is used, it is necessary to come to an agreement with the purchaser as to how much this bar is going to break, but if you simply agree that a bar suitable for the size of the casting must have 80,000 lbs. per sq. in. modulus of rupture, that is all there is to it.

# Effect of Molding Methods, Bar Diameter and Design on Physical Properties of Test Bars

By Garnet P. Phillips,* Moline, Ill.

**Abstract**

*The author has studied the effect of molding methods on transverse strength, the effect of bar diameter and design on tensile strength test bars and has done some investigation of the correlation of separately cast test bar results with those obtained on specimens cut from castings. In his investigation of molding methods, horizontally-cast test bars were superior to both vertically-cast test bars and to those cast at an angle with one end of the mold elevated. In his investigation of the effect of bar diameter on the tensile strength, he found that there was some increase in strength as the cast section was reduced. He cast two differently designed bars in his study of design of test bar on tensile strength, one designated as "proposed standard bar" and the other as "experimental tensile bar," and found that the latter type bar seemed to be the better suited to tensile test requirements. The latter portion of the paper is devoted to the correlation of physical properties of separately cast test bars and castings.*

## Part I—Effect of Molding Methods on the Transverse Strength of Gray Iron Test Bars

1. A series of gray iron test bars were cast in green sand molds by different methods to determine the effect of molding methods on the transverse strength of the bars. No dry sand molds were used since previous experience had shown that vertically-cast bars made in dry sand molds had the same defects as similar bars made in green sand molds and were more expensive to make. The fact that the majority of gray iron castings are made in green sand also made it seem advisable to cast test bars under the same conditions.

2. Various types of irons were used in the tests, ranging from fairly soft irons to irons of high alloy content.

* Metallurgist, Frank Foundries Corp.

Note: This paper was presented at the joint A.S.T.M.-A.F.A. meeting on Testing Cast Iron held at the 1934 Convention of A.F.A.

*Horizontally and Vertically Cast Bars*

3. The first series of bars was made by two methods. One method was to cast a bar vertically in an open, green-sand mold. The other method used consisted in pouring two bars horizontally in a green-sand mold. Molten metal entered the mold through a down sprue set over a two-part, ram-up core which formed the runner and which contained three pencil gates for each bar. The metal in this latter method thus was cleaned by passing through the pencil gates which acted as strainer cores. Each bar had an open riser set on the cope side at the end opposite the gated end to relieve pouring strain and to act as a "feeder."

4. The metal in the vertically-cast bars was not cleaned except by the lip of the pouring ladle. The wood pattern had to be rapped very slightly to remove it from the mold. The pipe used for a flask was drilled with holes at intervals of about 2-in. throughout the length and four rows of holes, equally spaced around the bar, were drilled for venting purposes. The mold used to make the horizontally-cast bars was made with a follow board and the two metal patterns were removed from the mold through the end without rapping and without removing the cope thus assuring true, round, mold cavities. The ends of the mold cavities were plugged with round cores after the patterns were withdrawn.

5. The metal used was melted in the temperature range 2790-2835 degrees Fahr. and was poured in the temperature range 2540-2590 degrees Fahr. The pouring rate for the vertically-cast bars was 1.3 lbs. of metal per second while the pouring rate of the horizontally-cast bars was 0.90 lbs. per second. The sand used tested about 6.0 per cent moisture, 16.0 permeability, and 3.1 lbs. per sq. in. in compression tests.

6. In pouring the bars, the molder filled a hand ladle from a full 900-lb. ladle as the latter passed his floor and immediately poured one of the "vertical" and one of the "horizontal" molds. A Leeds & Northrup optical pyrometer was used to determine temperatures.

7. The vertically-cast bar and one of the horizontally-cast bars were tested on a motor-driven, transverse testing machine on supports 12.0 ins. apart. Breaking load and deflection were noted and the diameters of the bars measured at the break, the load being corrected to a diameter of 1.25 ins. in all cases. Vertically-cast bars measured about 19.0 ins. in length while the horizontally-cast bars

measured about 15.0 ins. Both were approximately 1.25 ins. in diameter.

8. The test results, analyses obtained on the bars, and Brinell and Rockwell hardness values ("B" scale) are given in Tables 1 and 2.

9. The test results of the first series of bars showed that 60.0 per cent of the horizontally-cast bars were stronger than the vertically-cast bars. Eight of the vertically-cast bars were defective whereas none of the horizontally-cast bars were defective.

10. Since the transverse breaking load varies directly as the cube of the diameter for circular bars, the correction factors given in Table 3 were worked out for various bar diameters and used in calculating the corrected breaking loads given in Table 3.

*Horizontally and Vertically Poured A.S.T.M. Bars*

11. The second series of test bars were cast by the same

**Table 1**

CHEMICAL ANALYSES OF HORIZONTALLY AND VERTICALLY CAST TEST BARS 1.25 INS. DIAMETER, BROKEN ON 12 IN. SUPPORTS. SERIES 1.

| Date Cast | Bar No. | Si.- % | T. C.- % | C. C.- % | S.- % | P.- % | Mn.- % | Ni.- % | Cr.- % |
|---|---|---|---|---|---|---|---|---|---|
| 1-28-31 | 1 | 1.93 | 3.18 | 0.67 | 0.082 | 0.214 | 0.69 | 0.75 | 0.12 |
| | 2 | 1.97 | 3.30 | 0.64 | 0.088 | 0.214 | 0.71 | 0.92 | 0.14 |
| | 3 | 1.97 | 3.28 | 0.65 | 0.086 | 0.223 | 0.71 | 0.84 | 0.14 |
| | 4 | 1.95 | 3.24 | 0.66 | 0.096 | 0.239 | 0.69 | 0.85 | 0.10 |
| 1-30-31 | 1 | 1.93 | 3.27 | 0.62 | 0.064 | 0.242 | 0.71 | 0.91 | 0.15 |
| | 2 | 1.88 | 3.24 | 0.65 | 0.078 | 0.193 | 0.73 | 0.82 | 0.16 |
| | 3 | 1.97 | 3.25 | 0.63 | 0.074 | 0.244 | 0.74 | 0.87 | 0.18 |
| | 4 | 1.93 | 3.21 | 0.64 | 0.084 | 0.256 | 0.69 | 0.86 | 0.11 |
| 2- 2-31 | 1 | 1.90 | 3.23 | 0.64 | 0.087 | 0.273 | 0.67 | 0.77 | 0.11 |
| | 2 | 1.88 | 3.21 | 0.64 | 0.086 | 0.273 | 0.67 | 0.82 | 0.15 |
| | 3 | 1.88 | 3.30 | 0.62 | 0.086 | 0.269 | 0.68 | 0.74 | 0.14 |
| | 4 | 1.85 | 3.25 | 0.63 | 0.077 | 0.244 | 0.67 | 0.83 | 0.15 |
| 2- 4-31 | 1 | 2.00 | 3.29 | 0.61 | 0.074 | 0.168 | 0.69 | 0.86 | 0.20 |
| | 2 | 2.02 | 3.24 | 0.63 | 0.077 | 0.172 | 0.69 | 0.90 | 0.21 |
| | 3 | 1.95 | 3.28 | 0.64 | 0.073 | 0.192 | 0.70 | 0.99 | 0.18 |
| | 4 | 1.93 | 3.32 | 0.62 | 0.072 | 0.200 | 0.69 | 1.01 | 0.19 |
| 2- 6-31 | 1 | 2.07 | 3.35 | 0.63 | 0.080 | 0.215 | 0.71 | 1.54 | 0.60 |
| | 2 | 2.05 | 3.30 | 0.64 | 0.082 | 0.238 | 0.72 | 1.24 | 0.64 |
| | 3 | 2.07 | 3.36 | 0.66 | 0.083 | 0.251 | 0.71 | 1.29 | 0.63 |
| | 4 | 2.07 | 3.38 | 0.66 | 0.080 | 0.274 | 0.71 | 1.29 | 0.64 |
| 2- 9-31 | 1 | 2.05 | 3.38 | 0.67 | 0.079 | 0.208 | 0.69 | 1.10 | 0.60 |
| | 2 | 2.07 | 3.32 | 0.64 | 0.083 | 0.242 | 0.73 | 1.18 | 0.61 |
| | 3 | 2.05 | 3.24 | 0.64 | 0.078 | 0.181 | 0.71 | 1.30 | 0.64 |
| | 4 | 2.07 | 3.24 | 0.66 | 0.075 | 0.242 | 0.70 | 1.07 | 0.58 |
| 2-10-31 | 1 | 2.00 | 3.30 | 0.65 | 0.073 | 0.191 | 0.68 | 1.14 | 0.55 |
| | 2 | 1.97 | 3.30 | 0.66 | 0.076 | 0.221 | 0.65 | 1.13 | 0.64 |
| | 3 | 1.97 | 3.21 | 0.66 | 0.076 | 0.241 | 0.66 | 1.08 | 0.63 |
| | 4 | 2.02 | 3.28 | 0.65 | 0.078 | 0.225 | 0.69 | 1.04 | 0.64 |

**Table 2**

PHYSICAL TEST DATA ON HORIZONTALLY AND VERTICALLY CAST TEST BARS 1.25 INS. DIAMERTER BROKEN ON 12.0 IN. SUPPORTS. SERIES 1.

| Date Cast | Bar No. | Horizontally Cast Bars | | | | | | Vertically Cast Bars | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Hardness | | | | | | Hardness | |
| | | Load–Lbs. | Defl.–Inch | Bar Dia. | Corrected Load | Rockwell* "B" | Brinell | Load–Lbs. | Defl.–Inch | Bar–Dia. | Corrected Load | Rockwell* "B" | Brinell* |
| 1-28-31 | 1 | 4700 | 0.16 | 1.28 | 4357 | 93 | 196 | 4600 | 0.17 | 1.29 | 4163 | 94 | 192 |
| | 2 | 4443 | 0.15 | 1.28 | 4119 | 96 | 196 | 4630 | 0.18 | 1.28 | 4292 | 94 | 192 |
| | 3 | 4718 | 0.17 | 1.26 | 4595 | 95 | 192 | 4473 | 0.17 | 1.25 | 4473 | 95 | 196 |
| | 4 | 4462 | 0.16 | 1.26 | 4346 | 95 | 196 | 4427 | 0.16 | 1.23 | 4639 | 93 | 196 |
| 1-30-31 | 1 | 4500 | 0.16 | 1.28 | 4171 | 93 | 190 | 3744 | 0.13 | 1.26 | 3647 | 92 | 192 |
| | 2 | 4870 | 0.18 | 1.29 | 4407 | 93 | 192 | 4350 | 0.16 | 1.28 | 4032 | 93 | 192 |
| | 3 | 4657 | 0.18 | 1.28 | 4317 | 94 | 192 | 4555 | 0.17 | 1.23 | 4773 | 94 | 192 |
| | 4 | 4878 | 0.18 | 1.26 | 4751 | 95 | 192 | 3950 | 0.14 | 1.26 | 3847 | 95 | 196 |
| 2- 2-31 | 1 | 5400 | 0.19 | 1.26 | 5260 | 94 | 196 | 4767 | 0.18 | 1.25 | 4767 | 94 | 196 |
| | 2 | 5165 | 0.19 | 1.28 | 4788 | 93 | 196 | 4508 | 0.17 | 1.26 | 4391 | 95 | 202 |
| | 3 | 4527 | 0.17 | 1.28 | 4196 | 94 | 190 | 4457 | 0.18 | 1.26 | 4341 | 93 | 190 |
| | 4 | 4900 | 0.17 | 1.28 | 4542 | 93 | 192 | 4680 | 0.17 | 1.26 | 4558 | 94 | 192 |
| 2- 4-31 | 1 | 4500 | 0.16 | 1.26 | 4383 | 93 | 187 | 4700 | 0.17 | 1.25 | 4700 | 94 | 192 |
| | 2 | 4558 | 0.16 | 1.26 | 4439 | 93 | 187 | Bar defective—sand | | | | 93 | 192 |
| | 3 | 4613 | 0.18 | 1.28 | 4276 | 92 | 187 | Bar defective—sand | | | | 93 | 187 |
| | 4 | 4585 | 0.16 | 1.28 | 4250 | 91 | 187 | Bar defective—sand | | | | 92 | 187 |
| 2- 6-31 | 1 | 4210 | 0.14 | 1.28 | 3903 | 96 | 196 | 4306 | 0.14 | 1.25 | 4306 | 99 | 217 |
| | 2 | 4680 | 0.14 | 1.26 | 4558 | 98 | 207 | 4600 | 0.17 | 1.23 | 4821 | 99 | 217 |
| | 3 | 4675 | 0.14 | 1.26 | 4553 | 97 | 202 | Bar defective—sand | | | | 96 | 196 |
| | 4 | 4980 | 0.15 | 1.28 | 4616 | 97 | 202 | 4620 | 0.17 | 1.26 | 4500 | 98 | 207 |
| 2- 9-31 | 1 | 5015 | 0.17 | 1.26 | 4885 | 94 | 196 | 4584 | 0.16 | 1.23 | 4804 | 96 | 202 |
| | 2 | 4916 | 0.16 | 1.26 | 4788 | 97 | 196 | 4567 | 0.17 | 1.25 | 4567 | 97 | 202 |
| | 3 | 5051 | 0.17 | 1.26 | 4920 | 96 | 202 | 4512 | 0.17 | 1.22 | 4837 | 97 | 207 |
| | 4 | 4808 | 0.16 | 1.26 | 4683 | 96 | 207 | 4800 | 0.17 | 1.26 | 4675 | 94 | 202 |
| 2-10-31 | 1 | 5146 | 0.16 | 1.26 | 5012 | 98 | 212 | Bar defective—sand | | | | 96 | 207 |
| | 2 | 5338 | 0.16 | 1.26 | 5199 | 98 | 207 | Bar defective—shot and gas | | | | 98 | 228 |
| | 3 | 5148 | 0.14 | 1.28 | 4772 | 97 | 207 | Bar defective—shot | | | | 97 | 217 |
| | 4 | 5295 | 0.16 | 1.26 | 5157 | 96 | 207 | Bar defective—sand | | | | 98 | 217 |

*Brinell tests made at center of Section, and Rockwell tests around the Brinell impression. Each Rockwell value given is the average of four tests.

methods that were used for making the first series. The bar dimensions were changed to conform to present standard specifications of the American Society for Testing Materials, which call for a 1.20 in. diameter bar to be broken on supports 18.0 ins. apart. Metal patterns were used on both the vertically-cast and horizontally-cast bars in this series. One test bar only was made in each mold.

12. The pouring rate of the vertically-cast bars was 1.10 lbs. per second while that of the horizontally-cast bars was 0.96 lbs. per second. Other factors such as pouring conditions, metal temperatures and sand used were the same as in the first series of tests. Results obtained, chemical analyses and Brinell and Rockwell "B" hardness values are given in Tables 4 and 5.

13. Transverse test results on the second series of bars showed that 72.0 per cent of the horizontally-cast bars were stronger than the vertically-cast bars. There were two defective horizontally-cast bars and seven defective vertically-cast bars. The molder learned how hard to ram the horizontal molds when running the first series and the second series was practically all true to size. It was found almost impossible to uniformly ram the vertical molds hard enough to prevent some swelling during pouring. It also was found that the horizontally-cast bars were not swelled regardless of whether or not weights were used on the molds.

**Table No. 3**

CORRECTION FACTORS* FOR FORMER STANDARD ARBITRATION TEST BARS. A.S.T.M. FORMER STANDARD BAR 1.25 INCH DIAMETER. BROKEN ON SUPPORTS 12.0 INCHES APART. SERIES 1.

| Diameter of Bar | Correction Factor | | |
|---|---|---|---|
| 1.15 | 1.282 | 1.25 | 1.000 |
| 1.16 | 1.250 | 1.26 | 0.974 |
| 1.17 | 1.220 | 1.27 | 0.950 |
| 1.18 | 1.188 | 1.28 | 0.927 |
| 1.19 | 1.154 | 1.29 | 0.905 |
| 1.20 | 1.128 | 1.30 | 0.885 |
| 1.21 | 1.102 | 1.31 | 0.865 |
| 1.22 | 1.072 | 1.32 | 0.847 |
| 1.23 | 1.048 | 1.33 | 0.828 |
| 1.24 | 1.022 | 1.34 | 0.808 |
| 1.25 | 1.000 | 1.35 | 0.792 |

*Multiply breaking load by proper correction factor.

14. Table 6 gives the correction factors used to calculate the breaking loads of the bars to a bar diameter of 1.20 ins.

*Horizontally Poured and Inclined Bars*

15. The third series of test bars was cast horizontally and inclined. The molding method used was the same as that used to make the horizontally-cast bars in series one and two. One half of the bars were cast horizontally while in the other half the metal flowed up-hill during pouring. This was accomplished by elevating the riser end of the mold 1.75 ins. All bars in the third series were 1.20 in. diameter and broken on supports 18.0 ins. apart.

**Table 4**

CHEMICAL ANALYSES OF HORIZONTALLY AND VERTICALLY CAST BARS 1.20 INS. IN DIAMETER BROKEN ON 18.0 IN. SUPPORTS. SERIES 2.

| Date Cast | Bar No. | Si.- % | T. C.- % | C. C.- % | S.- % | P.- % | Mn.- % | Ni.- % | Cr.- % |
|---|---|---|---|---|---|---|---|---|---|
| 2-25-31 | 1 | 2.02 | 3.38 | 0.63 | 0.074 | 0.207 | 0.62 | 1.13 | 0.65 |
| | 2 | 2.02 | 3.38 | 0.62 | 0.072 | 0.207 | 0.62 | 1.13 | 0.65 |
| | 3 | 2.05 | 3.33 | 0.64 | 0.073 | 0.229 | 0.61 | 1.10 | 0.64 |
| | 4 | 2.05 | 3.33 | 0.64 | 0.072 | 0.229 | 0.61 | 1.10 | 0.64 |
| 2-27-31 | 1 | 1.90 | 3.36 | 0.65 | 0.065 | 0.214 | 0.63 | 1.11 | 0.60 |
| | 2 | 1.90 | 3.36 | 0.65 | 0.065 | 0.214 | 0.63 | 1.11 | 0.60 |
| | 3 | 1.88 | 3.28 | 0.67 | 0.062 | 0.218 | 0.63 | 1.16 | 0.66 |
| | 4 | 1.88 | 3.28 | 0.67 | 0.062 | 0.218 | 0.63 | 1.16 | 0.66 |
| 2-28-31 | 1 | 1.91 | 3.32 | 0.66 | 0.067 | 0.225 | 0.62 | 1.06 | 0.65 |
| | 2 | 1.91 | 3.32 | 0.66 | 0.067 | 0.225 | 0.62 | 1.06 | 0.65 |
| | 3 | 1.97 | 3.35 | 0.63 | 0.064 | 0.199 | 0.61 | 1.09 | 0.61 |
| | 4 | 1.97 | 3.35 | 0.63 | 0.064 | 0.199 | 0.61 | 1.09 | 0.61 |
| 3- 2-31 | 1 | 1.97 | 3.35 | 0.69 | 0.070 | 0.221 | 0.63 | 1.29 | 0.66 |
| | 2 | 1.97 | 3.35 | 0.69 | 0.070 | 0.221 | 0.63 | 1.29 | 0.66 |
| | 3 | 1.98 | 3.39 | 0.68 | 0.069 | 0.251 | 0.61 | 1.14 | 0.73 |
| | 4 | 1.98 | 3.39 | 0.68 | 0.069 | 0.251 | 0.61 | 1.14 | 0.73 |
| 3- 4-31 | 1 | 1.97 | 3.21 | 0.69 | 0.069 | 0.203 | 0.60 | 1.57 | 0.18 |
| | 2 | 1.97 | 3.21 | 0.69 | 0.069 | 0.203 | 0.60 | 1.57 | 0.18 |
| | 3 | 2.00 | 3.27 | 0.68 | 0.071 | 0.255 | 0.59 | 1.28 | 0.13 |
| | 4 | 2.00 | 3.27 | 0.68 | 0.071 | 0.255 | 0.59 | 1.28 | 0.13 |
| 3- 6-31 | 1 | 2.07 | 3.21 | 0.60 | 0.064 | 0.180 | 0.68 | 1.33 | 0.16 |
| | 2 | 2.07 | 3.21 | 0.60 | 0.064 | 0.180 | 0.68 | 1.33 | 0.16 |
| | 3 | 2.10 | 3.27 | 0.63 | 0.070 | 0.219 | 0.65 | 1.30 | 0.14 |
| | 4 | 2.10 | 3.27 | 0.63 | 0.070 | 0.219 | 0.65 | 1.30 | 0.14 |
| 3- 7-31 | 1 | 1.95 | 3.27 | 0.64 | 0.072 | 0.195 | 0.69 | 0.46 | 0.15 |
| | 2 | 1.95 | 3.27 | 0.64 | 0.072 | 0.195 | 0.69 | 0.46 | 0.15 |
| | 3 | 1.95 | 3.27 | 0.64 | 0.072 | 0.195 | 0.69 | 0.46 | 0.15 |
| | 4 | 1.95 | 3.27 | 0.64 | 0.072 | 0.195 | 0.69 | 0.46 | 0.15 |
| 3- 9-31 | 1 | 1.97 | 3.14 | 0.65 | 0.079 | 0.251 | 0.63 | 0.38 | 0.18 |
| | 2 | 1.97 | 3.14 | 0.65 | 0.079 | 0.251 | 0.68 | 0.38 | 0.18 |
| | 3 | 1.97 | 3.14 | 0.65 | 0.079 | 0.251 | 0.68 | 0.38 | 0.18 |
| | 4 | 1.97 | 3.14 | 0.65 | 0.079 | 0.251 | 0.68 | 0.38 | 0.18 |
| 3-11-31 | 1 | 2.06 | 3.20 | 0.61 | 0.074 | 0.202 | 0.69 | 1.03 | 0.70 |
| | 2 | 2.06 | 3.20 | 0.61 | 0.074 | 0.202 | 0.69 | 1.03 | 0.70 |
| | 3 | 2.06 | 3.20 | 0.61 | 0.074 | 0.202 | 0.69 | 1.03 | 0.70 |
| | 4 | 2.06 | 3.20 | 0.61 | 0.074 | 0.202 | 0.69 | 1.03 | 0.70 |

## Table 5

PHYSICAL TEST DATA ON HORIZONTALLY AND VERTICALLY CAST TEST BARS 1.20 INS. DIAMETER BROKEN ON 18.0 IN. SUPPORTS. SERIES 2.

| Date Cast | Bar No. | Horizontally Cast | | | | | | Vertically Cast | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Hardness | | | | | | Hardness | |
| | | Load–Lbs. | Defl.–Inch | Dia. Bar | Corrected Load | Rockwell "B"* | Brinell* | Load–Lbs. | Defl.–Inch | Dia. Bar | Corrected Load | Rockwell "B"* | Brinell* |
| 2-25-31 | 1 | 2550 | 0.30 | 1.20 | 2550 | 96 | 207 | 2522 | 0.28 | 1.22 | 2396 | 94 | 196 |
| | 2 | 2554 | 0.27 | 1.20 | 2554 | 94 | 197 | 2584 | 0.32 | 1.23 | 2400 | 93 | 196 |
| | 3 | 2564 | 0.30 | 1.20 | 2564 | 96 | 202 | 2600 | 0.30 | 1.23 | 2415 | 94 | 196 |
| | 4 | 2880 | 0.27 | 1.20 | 2880 | 96 | 207 | 2528 | 0.28 | 1.23 | 2348 | 94 | 196 |
| 2-27-31 | 1 | 2720 | 0.28 | 1.20 | 2720 | 96 | 207 | 2580 | 0.27 | 1.23 | 2397 | 94 | 196 |
| | 2 | 2810 | 0.30 | 1.20 | 2810 | 95 | 207 | 2610 | 0.27 | 1.23 | 2425 | 95 | 202 |
| | 3 | 2780 | 0.29 | 1.20 | 2780 | 93 | 192 | Bar defective—sand | | | | 95 | 207 |
| | 4 | 2690 | 0.27 | 1.20 | 2690 | 95 | 202 | 2600 | 0.24 | 1.20 | 2600 | 96 | 212 |
| 2-28-31 | 1 | 2655 | 0.28 | 1.20 | 2655 | 92 | 187 | 2660 | 0.28 | 1.20 | 2660 | 94 | 192 |
| | 2 | 2420 | 0.25 | 1.20 | 2420 | 95 | 202 | 2870 | 0.31 | 1.25 | 2537 | 94 | 192 |
| | 3 | 2910 | 0.28 | 1.20 | 2910 | 95 | 207 | Defective—Sand | | | | 95 | 202 |
| | 4 | 2710 | 0.26 | 1.20 | 2710 | 96 | 207 | 2370 | 0.21 | 1.23 | 2202 | 95 | 207 |
| 3- 2-31 | 1 | Bar defective—sand | | | | 95 | 202 | 2588 | 0.30 | 1.22 | 2459 | 95 | 196 |
| | 2 | 2440 | 0.29 | 1.20 | 2440 | 94 | 196 | 2618 | 0.30 | 1.22 | 2487 | 95 | 196 |
| | 3 | 2535 | 0.29 | 1.20 | 2535 | 95 | 202 | 2470 | 0.27 | 1.25 | 2183 | 93 | 187 |
| | 4 | 2175 | 0.25 | 1.20 | 2175 | 96 | 202 | 2580 | 0.28 | 1.23 | 2397 | 93 | 187 |
| 3- 4-31 | 1 | 2465 | 0.29 | 1.20 | 2465 | 94 | 196 | Bar defective—sand | | | | 94 | 196 |
| | 2 | 2650 | 0.31 | 1.20 | 2650 | 95 | 202 | 2377 | 0.26 | 1.23 | 2208 | 94 | 192 |
| | 3 | 2681 | 0.32 | 1.20 | 2681 | 95 | 196 | 2626 | 0.29 | 1.25 | 2321 | 95 | 202 |
| | 4 | 2530 | 0.29 | 1.20 | 2530 | 95 | 202 | 2572 | 0.28 | 1.22 | 2443 | 94 | 192 |
| 3- 6-31 | 1 | 2650 | 0.31 | 1.20 | 2650 | 94 | 196 | 2729 | 0.31 | 1.20 | 2729 | 95 | 202 |
| | 2 | 2584 | 0.29 | 1.20 | 2584 | 95 | 202 | 2551 | 0.28 | 1.22 | 2423 | 96 | 207 |
| | 3 | 2176 | 0.26 | 1.20 | 2176 | 94 | 196 | 2508 | 0.28 | 1.22 | 2383 | 94 | 192 |
| | 4 | 2500 | 0.29 | 1.20 | 2500 | 93 | 187 | 2778 | 0.29 | 1.25 | 2456 | 94 | 192 |
| 3- 7-31 | 1 | 2735 | 0.34 | 1.20 | 2735 | 94 | 196 | 2600 | 0.30 | 1.22 | 2470 | 94 | 192 |
| | 2 | 2774 | 0.34 | 1.20 | 2774 | 94 | 192 | 2562 | 0.29 | 1.22 | 2434 | 93 | 190 |
| | 3 | 2680 | 0.33 | 1.20 | 2680 | 94 | 196 | Bar defective—sand | | | | 95 | 202 |
| | 4 | Bar defective—gas | | | | 94 | 192 | Bar defective—sand | | | | 94 | 196 |
| 3- 9-31 | 1 | 2700 | 0.31 | 1.20 | 2700 | 95 | 202 | 2762 | 0.30 | 1.23 | 2566 | 94 | 196 |
| | 2 | 2745 | 0.31 | 1.20 | 2745 | 95 | 207 | 2530 | 0.27 | 1.22 | 2403 | 94 | 196 |
| | 3 | 2481 | 0.28 | 1.20 | 2481 | 95 | 202 | 2663 | 0.28 | 1.22 | 2530 | 94 | 192 |
| | 4 | 2500 | 0.28 | 1.20 | 2500 | 95 | 207 | Bar defective—shot | | | | 94 | 196 |
| 3-11-31 | 1 | 2504 | 0.31 | 1.20 | 2504 | 97 | 217 | Bar defective—sand | | | | 97 | 212 |
| | 2 | 2674 | 0.28 | 1.20 | 2674 | 97 | 212 | 2765 | 0.27 | 1.22 | 2627 | 95 | 212 |
| | 3 | 2820 | 0.31 | 1.20 | 2820 | 97 | 217 | 2790 | 0.28 | 1.22 | 2650 | 95 | 207 |
| | 4 | 2787 | 0.30 | 1.20 | 2787 | 98 | 217 | 2630 | 0.25 | 1.22 | 2498 | 96 | 207 |

*Tested at center of metal section at break.

**Table No. 6**

CORRECTION FACTORS* FOR STANDARD ARBITRATION TEST BARS FOR GRAY IRON. A.S.T.M. STANDARD BAR 1.20 IN. DIAMETER TO BE BROKEN ON 18.0 IN. SUPPORTS.

| Diameter of Bar | Correction Factor | Diameter of Bar | Correction Factor |
|---|---|---|---|
| 1.10 | 1.289 | 1.20 | 1.000 |
| 1.11 | 1.262 | 1.21 | 0.975 |
| 1.12 | 1.230 | 1.22 | 0.950 |
| 1.13 | 1.197 | 1.23 | 0.929 |
| 1.14 | 1.168 | 1.24 | 0.905 |
| 1.15 | 1.135 | 1.25 | 0.884 |
| 1.16 | 1.107 | 1.26 | 0.863 |
| 1.17 | 1.078 | 1.27 | 0.843 |
| 1.18 | 1.050 | 1.28 | 0.822 |
| 1.19 | 1.025 | 1.29 | 0.804 |
| 1.20 | 1.000 | 1.30 | 0.786 |

*Multiply breaking load by proper correction factor.

**Table 7**

CHEMICAL ANALYSIS OF INCLINED AND HORIZONTALLY CAST BARS, 1.20 IN. DIAMETER BROKEN ON 18.0 SUPPORTS.

| Date Cast | Bar No. | Si.-% | T. C.-% | C. C.-% | S.-% | P.-% | Mn.-% | Ni.-% | Cr.-% |
|---|---|---|---|---|---|---|---|---|---|
| 3-13-31 | 1 | 2.26 | 3.25 | 0.57 | 0.088 | 0.211 | 0.60 | 0.72 | 0.16 |
| | 2 | 2.05 | 3.30 | 0.64 | 0.064 | 0.180 | 0.60 | 1.33 | 0.57 |
| | 3 | 2.00 | 3.21 | 0.62 | 0.072 | 0.236 | 0.66 | 1.59 | 0.18 |
| | 4 | 2.46 | 3.52 | 0.48 | 0.078 | 0.251 | 0.64 | .... | .... |
| 3-14-31 | 1 | 2.00 | 3.33 | 0.60 | 0.074 | 0.185 | 0.65 | 1.15 | 0.62 |
| | 2 | 2.21 | 3.41 | 0.63 | 0.077 | 0.251 | 0.67 | 0.29 | 0.79 |
| | 3 | 2.44 | 3.48 | 0.46 | 0.090 | 0.240 | 0.70 | .... | .... |
| 3-16-31 | 1 | 2.26 | 3.21 | 0.57 | 0.088 | 0.184 | 0.59 | 0.76 | 0.17 |
| | 2 | 2.09 | 3.32 | 0.60 | 0.062 | 0.180 | 0.68 | 1.30 | 0.62 |
| | 3 | 2.09 | 3.22 | 0.55 | 0.072 | 0.200 | 0.64 | 1.56 | 0.18 |
| | 4 | 2.40 | 3.43 | 0.48 | 0.092 | 0.236 | 0.63 | .... | .... |
| 3-18-31 | 1 | 2.07 | 3.13 | 0.62 | 0.077 | 0.210 | 0.61 | 1.66 | 0.21 |
| | 2 | 2.40 | 3.47 | 0.47 | 0.089 | 0.252 | 0.64 | .... | .... |
| 3-20-31 | 1 | 2.33 | 3.30 | 0.61 | 0.078 | 0.199 | 0.64 | 0.78 | 0.18 |
| | 2 | 2.07 | 3.33 | 0.65 | 0.070 | 0.203 | 0.67 | 1.36 | 0.64 |
| | 3 | 2.05 | 3.28 | 0.61 | 0.075 | 0.211 | 0.65 | 1.53 | 0.19 |
| | 4 | 2.35 | 3.49 | 0.50 | 0.081 | 0.240 | 0.64 | .... | .... |
| 3-21-31 | 1 | 2.40 | 3.37 | 0.62 | 0.091 | 0.215 | 0.62 | 0.75 | 0.20 |
| | 2 | 2.14 | 3.27 | 0.64 | 0.070 | 0.195 | 0.62 | 1.66 | 0.56 |
| | 3 | 2.14 | 3.16 | 0.60 | 0.075 | 0.239 | 0.58 | 1.32 | 0.11 |
| | 4 | 2.44 | 3.47 | 0.48 | 0.075 | 0.263 | 0.66 | .... | .... |
| 3-23-31 | 1 | 2.24 | 3.43 | 0.60 | 0.094 | 0.210 | 0.59 | 0.67 | 0.17 |
| | 2 | 2.02 | 3.28 | 0.63 | 0.090 | 0.222 | 0.63 | 1.00 | 0.62 |
| | 3 | 2.13 | 3.25 | 0.59 | 0.071 | 0.269 | 0.58 | 1.47 | 0.12 |
| | 4 | 2.46 | 3.52 | 0.46 | 0.074 | 0.226 | 0.62 | .... | .... |
| 3-25-31 | 1 | 2.21 | 3.51 | 0.52 | 0.084 | 0.228 | 0.60 | 0.74 | 0.14 |
| | 2 | 1.97 | 3.36 | 0.64 | 0.059 | 0.212 | 0.66 | 1.16 | 0.67 |
| | 3 | 1.97 | 3.21 | 0.62 | 0.070 | 0.251 | 0.64 | 1.65 | 0.15 |
| | 4 | 2.30 | 3.48 | 0.46 | 0.077 | 0.267 | 0.62 | .... | .... |
| 3-27-31 | 1 | 2.16 | 3.49 | 0.54 | 0.075 | 0.224 | 0.64 | 0.71 | 0.15 |
| | 2 | 1.97 | 3.37 | 0.64 | 0.052 | 0.220 | 0.67 | 1.22 | 0.60 |
| | 3 | 1.90 | 3.22 | 0.56 | 0.064 | 0.240 | 0.64 | 1.73 | 0.27 |
| | 4 | 2.33 | 3.61 | 0.52 | 0.060 | 0.236 | 0.64 | .... | .... |

16. The test results, chemical analyses and Brinell and Rockwell "B" hardness values are given in Tables 7 and 8.

17. The test results showed that 57.0 per cent of the horizontally-cast bars were stronger than those cast with the molds inclined. Four of the horizontally-cast bars were defective due to sand inclusions while only one of the inclined bars was defective. Apparently there is no advantage in inclining the molds so that the metal flows up at an angle.

18. It was found that one cause of dirt in the mold cavities of the horizontal molds was that the riser cavity was too near the end of the mold and that when the cylindrical plug cores were put in after the patterns were withdrawn, a small amount of sand

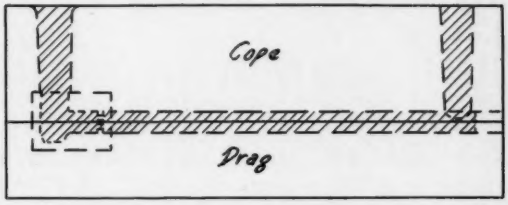

FIG. 1—ABOVE—MOLD USED FOR CASTING TEST BARS HORIZONTALLY. FIG. 2—RIGHT—MOLD USED FOR VERTICALLY CAST TEST BARS.

might have sheared off which may have appeared as an inclusion in the bar at the fracture after testing.

19. Sketches of the two types of molds used for the tests are given in Figs. 1 and 2. The mold used for the horizontally-cast bars measured 26.0 ins. in length by 10.0 ins. in width for the first series in which two bars were cast in one mold and 6.25 ins. in width for the molds in which one bar only was cast. The cope depth was 6.0 ins. and drag depth 4.0 ins. The down-sprue measured 1.625 ins. diameter at the top and 1.5 ins. diameter at the bottom, while the same dimensions for the riser pattern were 1.75 and 1.375 ins. respectively. The ram-up gate cores used measured 1.5 ins. thick, 4.0 ins. long and 3.75 ins. wide. The three gate-holes, one in the gate core in the cope and two in the gate core in the drag, which also strained the metal as it entered the mold cavity proper, were used. Each gate-hole had a diameter of 0.1875 in. The vertical molds used in the tests were sections of steel pipe 22.0 ins. long with an inside diameter of 3.0 ins.

**Table 8**

PHYSICAL TEST DATA ON INCLINED AND HORIZONTALLY CAST TEST BARS, 1.20 INS. DIAMETER, BROKEN ON 18.0 IN. SUPPORTS. SERIES 3.

| Date Cast | Bar No. | Molds Inclined | | | | | | Horizontally Cast | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Hardness | | | | | | Hardness | |
| | | Load-Lbs. | Defl.-Inch | Bar Dia. | Corrected Load | Rockwell "B"* | Brinell* | Load-Lbs. | Defl.-Inch | Bar Dia. | Corrected Load | Rockwell "B"* | Brinell* |
| 3-13-31 | 1 | 2295 | 0.31 | 1.20 | 2295 | 93 | 187 | 2374 | 0.31 | 1.20 | 2374 | 92 | 187 |
| | 2 | 2740 | 0.31 | 1.20 | 2740 | 97 | 207 | Bar defective—sand | | | | 97 | 212 |
| | 3 | 2536 | 0.31 | 1.20 | 2536 | 96 | 202 | 2633 | 0.31 | 1.20 | 2633 | 95 | 202 |
| | 4 | Bar defective—sand | | | | 85 | 150 | 1856 | 0.30 | 1.20 | 1856 | 84 | 149 |
| 3-14-31 | 1 | 2568 | 0.28 | 1.20 | 2568 | 97 | 212 | 2700 | 0.29 | 1.20 | 2700 | 97 | 212 |
| | 2 | 2480 | 0.25 | 1.20 | 2480 | 97 | 212 | 2610 | 0.28 | 1.20 | 2610 | 97 | 207 |
| | 3 | 2170 | 0.29 | 1.20 | 2170 | 87 | 163 | Bar defective—sand | | | | 87 | 166 |
| 3-16-31 | 1 | 2522 | 0.32 | 1.20 | 2522 | 93 | 192 | 2558 | 0.32 | 1.20 | 2558 | 94 | 196 |
| | 2 | 2600 | 0.28 | 1.20 | 2600 | 97 | 212 | 2570 | 0.28 | 1.20 | 2570 | 97 | 217 |
| | 3 | 2665 | 0.31 | 1.20 | 2665 | 96 | 207 | 2536 | 0.29 | 1.20 | 2536 | 96 | 207 |
| | 4 | 1885 | 0.32 | 1.20 | 1885 | 84 | 150 | 1905 | 0.31 | 1.20 | 1905 | 84 | 150 |
| 3-18-31 | 1 | 2780 | 0.33 | 1.20 | 2780 | 85 | 202 | 2420 | 0.24 | 1.20 | 2420 | 95 | 207 |
| | 2 | 1930 | 0.31 | 1.20 | 1930 | 83 | 146 | 1862 | 0.29 | 1.20 | 1862 | 82 | 146 |
| 3-20-31 | 1 | 2118 | 0.32 | 1.20 | 2118 | 88 | 153 | 2086 | 0.32 | 1.20 | 2086 | 88 | 159 |
| | 2 | 2712 | 0.29 | 1.20 | 2712 | 97 | 212 | 2754 | 0.29 | 1.20 | 2754 | 97 | 207 |
| | 3 | 2620 | 0.34 | 1.20 | 2620 | 94 | 202 | 2490 | 0.32 | 1.20 | 2490 | 93 | 196 |
| | 4 | 2019 | 0.31 | 1.20 | 2019 | 89 | 163 | 2030 | 0.30 | 1.20 | 2030 | 88 | 160 |
| 3-21-31 | 1 | 2057 | 0.32 | 1.20 | 2057 | 88 | 163 | 2097 | 0.33 | 1.20 | 2097 | 88 | 163 |
| | 2 | 2685 | 0.31 | 1.20 | 2685 | 95 | 207 | 2788 | 0.29 | 1.20 | 2788 | 96 | 212 |
| | 3 | 2780 | 0.31 | 1.20 | 2780 | 97 | 217 | 2892 | 0.34 | 1.20 | 2892 | 97 | 217 |
| | 4 | 2335 | 0.32 | 1.20 | 2335 | 90 | 183 | 2117 | 0.28 | 1.20 | 2117 | 90 | 183 |
| 3-23-31 | 1 | 2016 | 0.31 | 1.20 | 2016 | 85 | 170 | 1987 | 0.30 | 1.20 | 1987 | 86 | 170 |
| | 2 | 2764 | 0.30 | 1.20 | 2764 | 98 | 223 | 2780 | 0.29 | 1.20 | 2780 | 98 | 223 |
| | 3 | 2630 | 0.32 | 1.20 | 2630 | 95 | 207 | 2560 | 0.29 | 1.20 | 2560 | 95 | 207 |
| | 4 | 2140 | 0.32 | 1.20 | 2140 | 87 | 179 | Bar defective—sand | | | | 88 | 179 |
| 3-25-31 | 1 | 1870 | 0.31 | 1.20 | 1870 | 87 | 163 | 1900 | 0.30 | 1.20 | 1900 | 88 | 163 |
| | 2 | 2690 | 0.30 | 1.20 | 2690 | 98 | 217 | 2645 | 0.28 | 1.20 | 2645 | 98 | 212 |
| | 3 | 2720 | 0.32 | 1.20 | 2720 | 95 | 202 | 2820 | 0.33 | 1.20 | 2820 | 95 | 202 |
| | 4 | 1980 | 0.32 | 1.20 | 1980 | 85 | 156 | 2135 | 0.32 | 1.20 | 2135 | 86 | 159 |
| 3-27-31 | 1 | 1915 | 0.32 | 1.20 | 1915 | 86 | 170 | 1925 | 0.32 | 1.20 | 1925 | 86 | 170 |
| | 2 | 3022 | 0.33 | 1.20 | 3022 | 96 | 212 | 2928 | 0.31 | 1.20 | 2928 | 96 | 212 |
| | 3 | 2959 | 0.31 | 1.20 | 2959 | 96 | 212 | 2878 | 0.32 | 1.20 | 2878 | 96 | 212 |
| | 4 | 1925 | 0.33 | 1.20 | 1925 | 85 | 152 | Bar defective—sand | | | | 84 | 150 |

## CONCLUSIONS

20. The three series of tests indicate that, under the test conditions used, horizontally-cast bars are superior to both vertically-cast bars and bars cast in an inclined plane.

21. Acknowledgment is made for the courtesy shown by H. Bornstein, Director of Laboratories, Deere & Co., Moline, Ill., in kindly permitting use of the motor-driven, transverse testing machine for performing all the transverse tests given in this section of this report.

## PART II—EFFECT OF BAR DIAMETER ON TENSILE STRENGTH

22. Two sets of tests were made on bars of various "as cast" diameters. In the first series, four different alloy irons were used, while in the second series two different irons were used.

*Series 1.*

23. Four different irons were cast into three different diameter test bars to determine the variations in tensile strengths with variations in metal section. A transverse test bar of standard A.S.T.M. dimensions was also cast with each iron.

24. The data accumulated for each type of iron consisted of the following: Transverse strength of standard A.S.T.M. bar, tensile strength in bars of 0.60 ins., 0.875 in., and 1.20 in. diameter as cast, and Brinell and Rockwell "B" hardness of the metal in

**Table 9**

CHEMICAL COMPOSITION.

| No. | Si.-% | T. C.-% | S.-% | P.-% | Mn.-% | Ni.-% | Cr.-% | Mo.-% |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.94 | 3.28 | 0.094 | 0.252 | 0.56 | 1.46 | 0.58 | 0.00 |
| 2 | 1.97 | 3.24 | 0.098 | 0.242 | 0.58 | 0.79 | 0.31 | 0.00 |
| 3 | 1.90 | 3.25 | 0.096 | 0.240 | 0.59 | 0.53 | 0.17 | 0.00 |
| 4 | 1.90 | 3.25 | 0.096 | 0.240 | 0.59 | 0.81 | 0.17 | 0.75 |

DIVISION OF CARBON CONTENT.

| No. | 0.60 in. Dia. | | 0.875 in. Dia. | | 1.2 in. Dia. | |
|---|---|---|---|---|---|---|
| | G. C.-% | C. C. -% | G. C.-% | C. C.-% | G. C.-% | C. C.-% |
| 1 | 2.64 | 0.64 | 2.59 | 0.69 | 2.64 | 0.64 |
| 2 | 2.67 | 0.57 | 2.61 | 0.63 | 2.60 | 0.64 |
| 3 | 2.67 | 0.58 | 2.52 | 0.73 | 2.68 | 0.57 |
| 4 | 2.48 | 0.77 | 2.49 | 0.76 | 2.52 | 0.73 |

**Table 10**

TRANSVERSE LOAD AND DEFLECTION VALUES*

| No. | Load—Lbs. | Deflection—In. |
|---|---|---|
| 1 | 2660.0 | 0.28 (small flaw) |
| 2 | 2880.0 | 0.33 |
| 3 | 2760.0 | 0.32 |
| 4 | 3260.0 | 0.31 |

*Bars were 1.2 in. diameter and were broken on 18 in. supports.

**Table 11**

TENSILE STRENGTH VALUES.

| | Diameter As Cast | | |
|---|---|---|---|
| No. | 0.60 in. Lbs. per sq. in. | 0.875 in. Lbs. per sq. in. | 1.20 in. Lbs. per sq. in. |
| 1 | 40,370 | 42,240 | 37,660 |
| 2 | 39,398 | 40,060 | 37,520 |
| 3 | 38,102 | 37,960 | 36,440 |
| 4 | 52,100 | 49,080 | 47,300 |

**Table 12**

HARDNESS VALUES.

| | Diameter As Cast | | | | | |
|---|---|---|---|---|---|---|
| | 0.60" Dia. | | 0.875" Dia. | | 1.20" Dia. | |
| No. | Brinell | Rockwell "B" | Brinell | Rockwell "B" | Brinell | Rockwell "B" |
| 1 | 202.0 | 94.5 | 217.0 | 95.5 | 217.0 | 97.0 |
| 2 | 174.0 | 85.0 | 207.0 | 92.0 | 207.0 | 94.0 |
| 3 | 187.0 | 89.0 | 202.0 | 90.5 | 207.0 | 94.5 |
| 4 | 228.0 | 97.0 | 228.0 | 98.0 | 241.0 | 101.5 |

NOTE: Brinell was taken at center of each bar after grinding the fracture resulting from the tensile test. Four Rockwell "B" tests were made around the Brinell impression and the results given are the average of the four tests in each case.

bars of the diameters as given. Data obtained are given in Tables 9, 10, 11 and 12.

25. In the bars cast for tensile strength tests, those with a diameter of 0.600 in. were machined to 0.525 in. diameter; those with a diameter of 0.875 in. to a diameter of 0.800 in., while the bars cast to 1.20 in. diameter (transverse bars) were machined to 0.80 in. diameter before testing in tension.

*Discussion*

26. The 0.60 and the 0.875 in. diameter bars were cast in oil-sand cores according to proposed design of the A.S.T.M., although the smallest diameter bar so far proposed by the A.S.T.M. is 0.875 in.

27. The chemical analyses show that the 0.60 in. diameter

bars, with the exception of No. 4 (Ni-Mo-Iron) has combined carbons less than or equal to those of the bars of larger diameter, whereas we expected to find somewhat higher combined carbons in the smallest diameter bars. This is confirmed by the hardness test results. The tensile test results partly reflect these observations as the 0.60 in. diameter bars of 1 and 2 tested lower in tension than the 0.875 in. diameter bars, although they tested higher than the 1.20 in. diameter bars.

28. Another point to remember, when considering the tensile test result, is that the 1.2 in. diameter bars had much more stock removed in machining than the other two sets of bars. The standard A.S.T.M. bars were machined from the 1.2 in. diameter transverse bars. Table 13 gives the cross-sectional areas of the bars as cast and machined and the per cent the machined area is of the "as cast" cross-sectional areas.

29. Taking the test results obtained on the standard A.S.T.M. bars as 100.0 per cent (1.2 in. dia. bars) we get the results shown in Table 14.

30. As a matter of interest in drawing up specifications covering transverse strengths and tensile strengths for irons, the following data are given. The transverse strength of the metal on bars 1.20 in. diameter tested on 18.0 in. centers, the tensile strengths of the metal in different diameter bars, and the factor

**Table 13**

CROSS-SECTIONAL AREAS OF MACHINED AND AS CAST BARS.

| As cast | | Machined | | Per Cent of |
|---|---|---|---|---|
| Diameter | Area | Diameter | Area | As cast area. |
| 0.600 | 0.2828 | 0.525 | 0.2166 | 76.6 |
| 0.875 | 0.6025 | 0.800 | 0.5028 | 83.4 |
| 1.200 | 1.1314 | 0.800 | 0.5028 | 44.4 |

**Table 14**

TENSILE STRENGTH OF MACHINED BARS EXPRESSED AS PER CENT OF TENSILE STRENGTH OF STANDARD A.S.T.M. BARS.

| No. | 0.6 in. Dia. | 0.875 in. Dia. | 1.2 in. Dia. |
|---|---|---|---|
| 1 | 107.0 | 112.0 | 100.0 |
| 2 | 105.0 | 107.0 | 100.0 |
| 3 | 104.0 | 104.0 | 100.0 |
| 4 | 110.0 | 103.8 | 100.0 |

**Table 15**

FACTORS TO CONVERT TRANSVERSE TO TENSILE STRENGTH.

| Transverse | 0.6 In. Dia. | | 0.875 In. Dia. | | 1.20 In. Dia. | |
|---|---|---|---|---|---|---|
| Pounds | Tensile | Factor | Tensile | Factor | Tensile | Factor |
| 2660.0 | 40,370 | 15.2 | 42,240 | 15.9 | 37,660 | 14.2 |
| 2880.0 | 39,398 | 13.7 | 40,060 | 13.9 | 37,520 | 13.0 |
| 2760.0 | 38,102 | 13.8 | 37,960 | 13.8 | 36,440 | 13.0 |
| 3260.0 | 52,100 | 16.0 | 49,080 | 15.1 | 47,300 | 14.5 |

by which the transverse strength may be multiplied to give the tensile strength in a given section are shown in Table 15 for the test results given in this report.

31. It might have been found, if the amount of stock removed from the 1.2 in. diameter bars had been of the same order as that removed from the smaller diameter bars, that the increase in strengths of the smaller bars would have been less. However, the metals used were all fairly low-carbon, alloy irons that would not reflect the differences in sections as much as higher carbon, softer irons.

*Series 2*

32. A transverse test bar of standard A.S.T.M. dimensions, 1.2 in. diameter and 21.0 ins. long, and a tensile specimen with a diameter of 0.675 in., were each cast with two irons. The tests were made to get further compartive data on the tensile strengths of different irons cast in various sections. Data obtained are given in Tables 16, 17, 18 and 19.

**Table 16**

CHEMICAL COMPOSITION.

| No. | Si.– % | C. % | S.– % | P.– % | Mn.– % | Ni.– % | Cr. % |
|---|---|---|---|---|---|---|---|
| 1 | 2.05 | 3.29 | 0.072 | 0.229 | 0.62 | 1.26 | 0.61 |
| 2 | 2.04 | 3.30 | 0.091 | 0.239 | 0.61 | 1.28 | 0.74 |

CARBON DIVISION

| No. | 1.20 In. Dia. | | 0.675 In. Dia. | |
|---|---|---|---|---|
| | G. C.– % | C. C.– % | G. C.– % | C. C % |
| 1 | 2.64 | 0.65 | 2.64 | 0.65 |
| 2 | 2.60 | 0.70 | 2.52 | 0.78 |

**Table 17**

TRANSVERSE LOAD AND DEFLECTION VALUES.*

| Bar No. | Load– Lbs. | Deflection– In. |
|---|---|---|
| 1 | 2660 | 0.28 |
| 2 | 2860 | 0.29 |

*Bars were 1.2 in. diameter and broken on 18 in. supports.

**Table 18**

TENSILE STRENGTH VALUES.

| No. | 1.20 In. Dia. As cast– Lbs. per sq. in. | 0.675 In. Dia. As cast– Lbs. per sq. in. |
|---|---|---|
| 1 | 40,000 | 43,856 |
| 2 | 41,160 | 42,695 |

**Table 19**

HARDNESS VALUES.

| No. | 1.20 In. Dia. | | 0.675 In. Dia. | |
|---|---|---|---|---|
| | Brinell | Rockwell "B" | Brinell | Rockwell "B" |
| 1 | 207.0 | 93.5 | 223.0 | 95.2 |
| 2 | 212.0 | 94.0 | 228.0 | 95.7 |

**Table 20**

COMPARISON OF BARS ON PER CENT OF TENSILE STRENGTH BASIS.

| No. | 1.20 In. Dia. As cast | 0.875 In. Dia. As cast |
|---|---|---|
| 1 | 100.0 | 109.6 |
| 2 | 100.0 | 103.7 |

**Table 21**

COMPARISON OF CROSS-SECTIONAL AREA OF AS CAST AND MACHINED BARS.

| As Cast | | Machined | | Per Cent of |
|---|---|---|---|---|
| Dia. | Area | Dia. | Area | As Cast Area |
| 1.200 | 1.1314 | 0.800 | 0.5028 | 44.4 |
| 0.675 | 0.3580 | 0.600 | 0.2828 | 79.0 |

**Table 22**

FACTORS FOR CONVERTING TRANSVERSE TO TENSILE STRENGTH.

| Transverse—Lbs. | 1.20 In. Dia. | | 0.675 In. Dia. | |
|---|---|---|---|---|
| 2660 | 40,000 | 15.1 | 43,856 | 16.5 |
| 2860 | 41,160 | 14.4 | 42,695 | 15.5 |

33. Standard A.S.T.M. tensile test specimens of 0.80 in. diameter at center were machined from the 1.20 in. diameter test bars. The 0.675 in. diameter tensile test specimens were machined to 0.600 in. diameter before testing. All bars had threaded ends. Tensile test data are shown in Table 18.

34. Hardness tests were made on the smoothly ground ends of the fractured bars. A Brinell test was made at the center of the bar and four Rockwell "B" tests were made around each Brinell impression. The Rockwell "B" figures given in Table 19 are the average of the four tests in each case.

35. Taking the tensile results on the 1.20 in. diameter bars as 100.0 per cent, the results shown in Table 20 are obtained.

36. Cross-sectional areas of the bars as cast and machined, as well as the percentage of the machined area of the as-cast area are given in Table 21.

37. Factors by which the transverse strengths may be multiplied to obtain the tensile strengths in each test are given in Table 22 for the test results given in this section of this report.

*Discussion*

38. Test results show some gain in tensile strength as the as-cast section is reduced as well as an increase in hardness. These were expected results.

## PART III—EFFECT OF TEST BAR DESIGN ON TENSILE STRENGTH

39. Tensile tests were made on seven sets of tensile test specimens all of which had a diameter at the smallest cross section of 0.875 in. as cast. The two bars of each set were of different design in respect to the length of the 0.875 in. diameter parallel section as cast and the 0.800 in. diameter parallel section as machined. Tensile tests were also made on standard A.S.T.M. bars of 0.800 in. diameter machined from 1.20 in. diameter transverse bars cast with the same metals.

40. One bar of each set had an 0.875 in. parallel section length of one-quarter in. as cast and an 0.800 in. parallel section length of one-quarter in. as machined. The other bar of each set had the corresponding lengths equal to the diameter both in the as cast and machined condition. Details of the two types of bars are given in Figs. 3 and 4. For identification purposes, the former type is called the "proposed standard bar", while the latter type is called "experimental tensile bar."

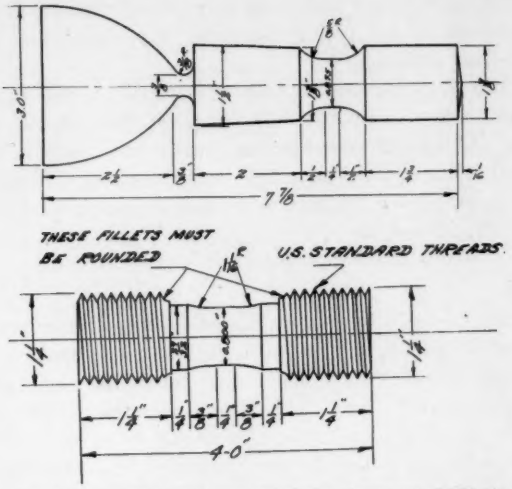


FIG. 3—ABOVE—PATTERN DRAWING FOR PROPOSED STANDARD 0.875 IN. DIAMETER, GRAY IRON TENSILE TEST BAR. BELOW—MACHINE DRAWING FOR SAME BAR.

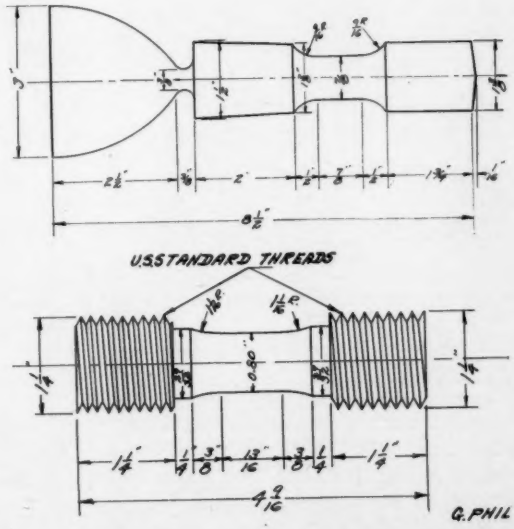


FIG. 4—ABOVE—PATTERN DRAWING FOR 0.875 IN. EXPERIMENTAL GRAY IRON TEST BAR IN WHICH PARALLEL SECTION LENGTH EQUALS DIAMETER. BELOW—MACHINE DRAWING FOR SAME BAR.

41. The cast tensile bars were all cast in baked oil-sand molds made in two halves and pasted together. The molds were clamped together before pouring.

42. The first five sets of bars were each poured with a different type of iron while the last two sets were poured with the same ladle of iron. Transverse test bars were cast with each set of tensile test bars. The transverse bars were cast horizontally in green sand, as shown in Fig. 5. Data obtained are shown in Tables 23, 24, 25 and 26.

*Discussion*

43. All of the tensile bars failed at an intersection of the parallel section and the radius with the one exception noted. All of the "experimental" bars had higher tensile strengths than the "proposed standard" bars. This held true even in the bars that had defects in them. All the cast tensile bars, with defectives omitted, tested higher than the bars machined from transverse bars.

44. Assuming that the tensile strength of the bars machined from the transverse bars were 100 per cent and omitting defective bars, the results may be expressed as shown in Table 27.

45. On the basis of the results obtained from these few tests, the design of the "experimental" bars appears to be better suited to tensile test requirements than the design of the "proposed stand-

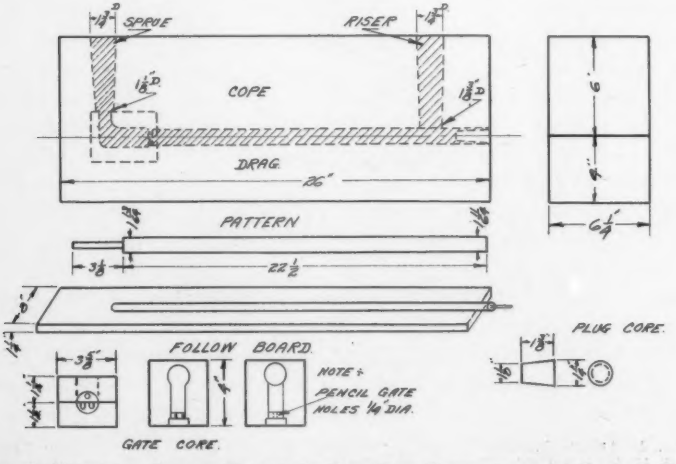


FIG. 5—METHOD OF CASTING TRANSVERSE TEST BARS HORIZONTALLY IN GREEN SAND.

**Table 23**

CHEMICAL COMPOSITION.*

| No. | Si.– % | T.C.– % | G.C.– % | C.C.– % | S.– % | P.– % | Mn.– % | Ni.– % | Cr.– % | Mo.– % |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.99 | 3.20 | 2.42 | 0.78 | 0.099 | 0.193 | 0.65 | 1.22 | 0.89 | .... |
| 2 | 2.09 | 3.29 | 2.64 | 0.65 | 0.085 | 0.237 | 0.57 | 0.80 | 0.27 | .... |
| 3 | 1.95 | 3.18 | 2.62 | 0.56 | 0.110 | 0.186 | 0.60 | 1.60 | 0.31 | .... |
| 4 | 2.13 | 3.25 | 2.58 | 0.57 | 0.104 | 0.229 | 0.62 | 0.86 | 0.29 | .... |
| 5 | 2.23 | 3.63 | 3.08 | 0.55 | 0.086 | 0.274 | 0.60 | 0.21 | 0.01 | .... |
| 6–1 6–2 | 2.05 | 3.25 | 2.61 | 0.64 | 0.071 | 0.244 | 0.58 | 0.79 | 0.18 | 0.75 |

NOTE.—Graphite determined by combustion.
*Analysis determined on samples drilled from transverse test bars.

**Table 24**

TRANSVERSE LOAD AND DEFLECTION VALUES.*

| No. | Load– Lbs. | Defl.– In. |
|---|---|---|
| 1 | 2540 | 0.25 |
| 2 | 2430 | 0.33 |
| 3 | 2740 | 0.29 |
| 4 | 2650 | 0.31 |
| 5 | 1700 | 0.28 |
| 6–1 | 3350 | 0.34 |
| 6–2 | 3240 | 0.34 |

NOTE.—6–1 and 6–2 same metal.
*Bars 1.2 in. diameter broken on 18 in. supports.

**Table 25**

TENSILE STRENGTH VALUES.

| Set No. | Proposed Standard Bar– Lbs. per sq. in. | Experimental Bar– Lbs. per sq. in. | Bar from Transverse Bar– Lbs. per sq. in. |
|---|---|---|---|
| 1 | 38,765 | 41,924 | 34,380[1] |
| 2 | 37,490 | 40,683 | 31,780 |
| 3 | 39,600 | 40,843 | 36,900 |
| 4 | 32,948 | 34,340* | 33,320 |
| 5 | 21,513 | 21,720* | 20,900 |
| 6–1 | 44,270 | 46,990 | 43,080 |
| 6–2 | 44,260 | 45,290 | 43,880 |

[1]Broke in threads. Load calculated for 0.800 in. diameter.
*Small gas hole in fracture.
NOTE.—Bar diameter measured to the nearest 0.001 in. Diameter varied from 0.793 to 0.800 in.

ard'' bars. This may possibly be due to the better resistance of the longer parallel sections of the bars to slight bending stresses encountered in testing where the tensile stress applied is not perfectly axial.

**Table 26**

HARDNESS VALUES.

| Set No. | Transverse Bars | | Tensile Bars | | | |
|---|---|---|---|---|---|---|
| | | | Proposed Standard Bar | | Experimental Bar | |
| | Brinell | Rockwell "B" | Brinell | Rockwell "B" | Brinell | Rockwell "B" |
| 1 | 217.0 | 98.0 | 235.0 | 97.5 | 235.0 | 98.5 |
| 2 | 180.0 | 88.6 | 207.0 | 93.5 | 223.0 | 95.2 |
| 3 | 207.0 | 93.5 | 217.0 | 96.0 | 212.0 | 93.7 |
| 4 | 196.0 | 90.3 | 196.0 | 89.0 | 202.0 | 92.7 |
| 5 | 137.0 | 71.6 | 137.0 | 73.7 | 149.0 | 75.5 |
| 6-1 | 223.0 | 94.5 | 223.0 | 97.2 | 228.0 | 97.5 |
| 6-2 | | | 228.0 | 97.2 | 235.0 | 98.5 |

NOTE.—Brinell tests made on smoothly ground fractures. Four Rockwell "B" Hardness tests made around each Brinell. Rockwells shown above are the average of four tests in each case.

**Table 27**

COMPARISON OF BARS ON PER CENT OF TENSILE STRENGTH OF 1.2 IN. DIAMETER.

| Set No. | Bars from Transverse Bars | Proposed Standard Bar | Experimental Bar |
|---|---|---|---|
| 1 | 100.0 | 113.0 | 122.0 |
| 2 | 100.0 | 118.0 | 128.0 |
| 3 | 100.0 | 107.0 | 111.0 |
| 5 | 100.0 | 103.0 | ..... |
| 6–1 | 100.0 | 103.0 | 109.0 |
| 6–2 | 100.0 | 101.0 | 103.5 |

**Table 28**

CHEMICAL COMPOSITION.

| No. | Si.- % | T. C.- % | G. C.- % | C. C.- % | Sl- % | P.- % | Mn.- % | Ni.- % | Cr.- % | Mo.- % |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.46 | 2.72 | 2.05 | 0.67 | 0.024 | 0.160 | 0.79 | 0.00 | 0.00 | 0.53 |
| 2 | 1.96 | 3.14 | 2.41 | 0.73 | 0.053 | 0.173 | 0.62 | 1.52 | 0.13 | 1.18 |
| 3 | 1.94 | 3.20 | 2.20 | 1.00 | 0.091 | 0.196 | 0.63 | 1.54 | 1.14 | 0.00 |
| 4 | 1.85 | 3.37 | 2.66 | 0.71 | 0.058 | 0.180 | 0.57 | 1.58 | 0.42 | 1.25 |
| 5 | 1.47 | 3.36 | 2.49 | 0.87 | 0.069 | 0.190 | 0.58 | 1.56 | 0.32 | 1.40 |
| 6 | 1.74 | 3.16 | 2.46 | 0.70 | 0.053 | 0.189 | 0.68 | 1.06 | 0.21 | 0.77 |

NOTE.—Graphite determined by combustion.

## PART IV—CORRELATION OF PHYSICAL PROPERTIES OF SEPARATELY CAST TEST BARS AND CASTINGS

46. Tables 28, 29, 30 and 31 give data on the physical properties of separately cast test bars and castings poured with various electric-furnace and cupola-melted alloy irons.

*Discussion*

47. It should be noted that all Rockwell "B" tests given

**Table 29**

TENSILE STRENGTH VALUES.

| Iron No. | Cast Tensile Bars 0.875 In. Diameter "As Cast"; 0.800 In. Diameter Machined. Lbs. per sq. in. | 1.2 In. Transverse Bars Machined to 0.800 In. Diameter. Lbs. per sq. in. | Casting Wall Ins. | Casting Weight Lbs. | Tensile Strength Lbs. per sq. in. |
|---|---|---|---|---|---|
| 1 | 49,650 | ..... | 0.875 | 128 | 44,150 |
| 2 | 56,720 | 55,520 | 0.687 | 109 | 56,100 |
| 3 | 44,570 | 42,260 | 0.687 | 109 | 40,000 |
| 4 | 48,648 | 53,080 | 0.687 | 109 | 48,070 |
| 5 | 55,347 | 53,780 | 0.687 | 109 | 52,440 |
| 6-1 | 53,010 | 51,900 | 0.687 | 109 | 49,592 |
| 6-2 | 53,010 | 51,900 | 1.280 | 192 | 50,325 |

**Table 30**

HARDNESS VALUES.

| Iron No. | 0.875 In. Tensile Bar Rockwell "B" | 0.875 In. Tensile Bar Brinell | 1.20 In. Transverse Bar Rockwell "B" | 1.20 In. Transverse Bar Brinell | Casting Wall-Ins. | Casting Rockwell "B" | Casting Brinell |
|---|---|---|---|---|---|---|---|
| 1 | 102.0 | 255 | 101.5 | 255 | 0.875 | 96.0 | 238 |
| 2 | 99.5 | 242 | 99.5 | 241 | 0.687 | 99.0 | 241 |
| 3 | 102.0 | 269 | 100.2 | 255 | 0.687 | 102.0 | 248 |
| 4 | 101.2 | 255 | 106.7 | 311 | 0.687 | 97.0 | 241 |
| 5 | 101.2 | 255 | 109.5 | 332 | 0.687 | 100.0 | 240 |
| 6-1 | 96.4 | 235 | 94.5 | 223 | 0.687 | 94.5 | 217 |
| 6-2 | 96.4 | 235 | 94.5 | 223 | 1.280 | 95.0 | 217 |

NOTE.—Brinell was taken at center of each bar after grinding the fracture resulting from the tensile test. Four Rockwell "B" tests were made around the Brinell impression and the results given are the average of the four tests in each case.

**Table 31**

TRANSVERSE LOAD AND DEFLECTION DATA.

| Iron No. | 1.20 In. Diameter Bar Load-Lbs. | 18.0 In. Supports-Deflection-In. |
|---|---|---|
| 1 | 2990 | 0.230 |
| 2 | 3760 | 0.390 |
| 3 | 2880 | 0.250 |
| 4 | 3600 | 0.450 |
| 5 | 3500 | 0.440 |
| 6 | 3430 | 0.340 |

*Bars were 1.2 in. diameter and were broken on 18 in. supports.

above are the average of at least four tests, and the transverse and tensile tests on bars, the average of two tests, while the tensile tests on castings were in most cases single tests on bars of only 0.25 in. diameter in the parallel section, with the exception of No. 6-2 which is the average of duplicate tests on 0.800 in. diameter bars.

48. Bearing in mind that the tensile bars machined from castings were in most cases only 0.25 in. diameter and thus were only a comparatively small percentage of the total casting wall cross-sectional area, it is seen that the tensile strengths of the separately cast bars and of the bars cut from castings show relatively good agreement. The tests show, in a general way, a relation between Brinell hardness and tensile strength, although this is not always true.

49. All the irons given in Tables 28, 29, 30 and 31 were of relatively high hardness and this probably accounts for the rather small differences found in the tensile strengths. In other words the properties were not greatly affected by the cooling rates.

50. A study of the data shows that no definite conclusions may be drawn to cover all the test data as to relations between size of bar and section of castings.

51. The tests, from which the above data were obtained, were made in 1932 and 1933.

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## DISCUSSION

R. S. MACPHERRAN[1]: We had very good success with the test bar used by Mr. Phillips but modified to a very minor degree. Instead of stopping the end with a fire clay plug, we paste a core at the end of the casting and put a brick under the end of the mold to pitch it up a little. This has the effect of pouring the mold on a slight slant. We pour about 15 or 20 lbs. of iron through and never get a defective bar. We have run 15 to 25 bars and they are all sound. We are inclined to prefer the transverse type of bar to the old vertical type.

MEMBER: Were the bars molded in green or dry sand and how were they cleaned?

MR. PHILLIPS: All bars were made in green sand and no facing was used. With regard to cleaning, our practice is to tumble all test bars as we do castings. We feel that we should clean the test bars in the same manner as we do the castings. We have never run any tests on those bars as cast without any cleaning as against those that are cleaned.

CHAIRMAN J. T. MACKENZIE[2]: When you go to high strength iron and especially when you get into real white iron, the horizontally cast bar used by Mr. Phillips will give shrinkage at the top. This is increasingly true with the larger sizes of bars. The method makes a very nice ¾-in. diameter bar and a good 1.2-in. diameter bar but on a 4-in. diameter bar, the shrinkage at the top becomes quite serious. You get a better

[1] Allis-Chalmers Mfg. Co., Milwaukee, Wis.
[2] American Cast Iron Pipe Co., Birmingham, Ala.

4-in. diameter bar by casting it vertically than by the horizontal casting method. It is probably the reverse on the 1.2-in. diameter bar. I would like to know if anybody else has tried to make a big bar or if anybody has had any trouble with shrinkage in the horizontally poured bars?

MR. PHILLIPS: We have tried to use the horizontally cast bar in the production of metal to be annealed. The metal was cast white and given a short cycle anneal. In no case have we obtained sound test bars, in fact, we have not tried to make transverse test bars with that type of metal. We have gone to the malleable type of tensile test bar about 5-in. diameter as cast. We have made a few 3-in. diameter transverse test bars tested on 24-in. centers and have had the trouble that Mr. MacKenzie mentioned, getting some shrinkage on the cope side about the center of the bar. This defect is quite a nuisance in calculating results.

MR. MACPHERRAN: That is why we make our bars on a slight slant. Any little depression will come beyond where the stress comes, at the top of the bar which is not under stress. We can make 2-in. diameter bars quite easily, cast flat.

# Chilling Properties of Cast Iron

By W. H. Spencer,* Birmingham, Ala.

**Abstract**

*Two sizes of chill test specimens were used. One was 1-1/2 x 1-1/2 x 6 in. and the other was 1-1/2 x 3 x 6 in. Each had a 1-1/2 in. face against the chilling block, but in one case the depth was 1-1/2 in., and in the other case, 3 in. It was found that variations in chill depth due to changes in pouring temperature were very slight. Sand also seemed to have little or no effect on depth of chill. The effect of composition on chill may be summarized as follows: Chill depth was increased by high sulphur or manganese, and by ladle additions of antimony, bismuth, brass, cadmium, cobalt, lead, tin, and vanadium. It was decreased by high silicon or total carbon, or phosphorus. The chill test indicated qualitatively the ratio of silicon to total carbon, and of manganese to sulphur. It can be used for shop control of mixtures and melting operations.*

1. The chilling tendency of cast iron is of great importance in practically all branches of the gray and chilled iron industry. In the making of chilled irons, such as rolls, car wheels, etc., the importance of chill depth is obvious. In gray iron work requiring machining or enameling, the tendency of the metal to chill or form hard spots must be regulated. The casting qualities and physical properties of the metal are related to its chilling tendency.

2. The data presented in this paper were obtained from over 1500 tests conducted during a period of seven years. Cupolas of 18 in., 24 in., 56 in., 72 in., and 72 x 102 in. were used as melting units. An electric furnace was used in one or two instances. In the cupolas, the fuel was coke in all cases, but included blast furnace and pitch cokes as well as representative foundry cokes. Bed height and blast pressure varied from test

* Metallurgist, American Cast Iron Pipe Co.

Note: This is one of the papers presented at the joint A.S.T.M.-A.F.A. session on Testing Cast Iron at the 1934 convention of A.F.A.

to test. The pig irons included regular foundry irons, Bessemer iron, Welsh pig, Mayari pig, Oslebhausen pig, charcoal pig, etc. The proportions of pig, scrap and steel varied from none to 100 per cent of each in different heats.

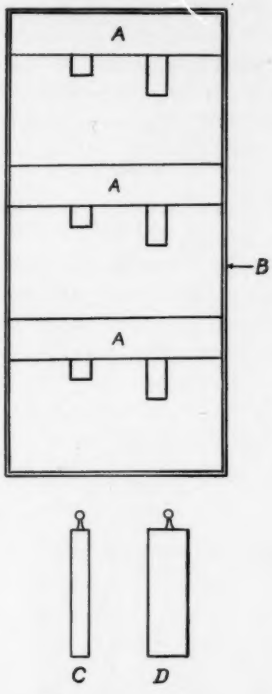



FIG. 1—CHILL TEST OUTFIT SHOWING CHILL BLOCKS (A) AND POSITION OF TEST BARS.

3. Fig. 1 shows the chill test outfit used in this work. The chilling block (A) was cast iron with a machined face. It was 3 x 6 x 12 in., with an L-shaped base 2 x 6¼ x 12 in. Three of these chilling blocks were placed in a close fitting cast iron frame (B), which held the sand in position. Two patterns were used; one (C) being 1½ x 1½ x 10 in., and the other (D) being 1½ x 3 x 10 in. These gave two chill specimens for each test, both having the 1½ in. face against the chilling block, but one being 1½ in. thick while the other was 3 in. thick. The chill

specimen molds were rammed in green sand. After pouring, the specimen was allowed to cool below a blue heat before being removed from the sand.

4. When thoroughly cold, the chill specimens were broken transversely, as close to the middle as possible. The depth from the chilled face to the first gray iron and to the last white iron was measured on each size of chill specimen. Measurements were made at one-third points along the face of the chill specimens and averaged. For each test there were four measurements recorded, first gray and last white on each specimen.

**Table 1**

STEP BAR AND CHILL TEST RESULTS

| Test No. | Chill Depth in ins.—1½ x 1½ x 6 in. Bar | | Step Bar Results | |
|---|---|---|---|---|
| | First Gray | Last White | Step No. | Appearance |
| 1 | 0.21 | 0.45 | 1 | solid chill |
| | 0.20 | 0.47 | 2 | very deep chill |
| | | | 3 | slight chill at edge |
| 2 | 0.03 | 0.11 | 1 | solid chill |
| | 0.03 | 0.11 | 2 | slight chill |
| | | | 3 | no chill |
| 3 | 0.03 | 0.12 | 1 | mottled |
| | 0.03 | 0.11 | 2 | slight chill |
| | | | 3 | very slight chill at edge |
| 4 | 0.37 | 0.90 | 1 | solid chill |
| | 0.38 | 0.91 | 2 | medium chill |
| | | | 3 | no chill |
| 5 | 0.39 | 1.02 | 1 | solid chill |
| | 0.43 | 1.01 | 2 | mottled |
| | | | 3 | slight chill |
| 6 | 0.09 | 0.18 | 1 | solid chill |
| | 0.11 | 0.20 | 2 | slight chill |
| | | | 3 | no chill |
| 7 | 0.20 | 0.28 | 1 | solid chill |
| | 0.19 | 0.31 | 2 | slight chill |
| | | | 3 | no chill |
| 8 | 1.21 | 1.50 | 1 | did not run |
| | 1.10 | 1.50 | 2 | short—solid chill |
| | | | 3 | solid chill |
| 9 | 0.01 | 0.07 | 1 | blown—mere shell |
| | 0.00 | 0.05 | 2 | blown—mere shell |
| | | | 3 | blown—mere shell |

5. The step bar was tested as a measure of the tendency of cast iron to chill. Molding conditions had a great effect on the results and there was no exact way to express the results in figures. Some step bar results are given in Table 1, with the measurements from the method adopted. Tests No. 8 and 9 gave defective or incomplete castings in step bars.

6. A variation of the chill test was tried. The difference was in the size and shape of the specimen, which had a 5/8-in. face against the chilling block and a larger, rounded backfield. Results from this test were satisfactory, except that fins tended to make large comparative differences with light chilling irons, due to the narrow face.

## TESTS OF ADOPTED METHOD

7. The method adopted was tested for sensitivity to changes in the casting conditions. Since the 3-in. thickness of the chilling block was constant for all the tests and was considered ample, no tests with other thicknesses of block were made.

8. Table 2 gives chill test results on cast irons poured in the range of temperatures ordinarily occurring with cupola melted metal. In general, the medium pouring temperatures gave deepest chilling and hot pouring gave lightest chilling. The total

**Table 2**

EFFECT OF POURING TEMPERATURE ON DEPTH OF CHILL

| Pouring Temperature—Deg. Fahr. | Chill Depth in In. First Gray | Last White | Si.— % | S.— % | Mn.— % | P.— % | T. C.— % |
|---|---|---|---|---|---|---|---|
| 2665 | 0.05 | 0.13 | 1.86 | 0.068 | 0.53 | 0.65 | 3.54 |
| 2455 | 0.06 | 0.11 | 1.86 | 0.068 | 0.53 | 0.65 | 3.54 |
| 2630 | 0.21 | 0.45 | 1.64 | 0.073 | 0.66 | 0.60 | 3.39 |
| 2590 | 0.20 | 0.47 | 1.64 | 0.073 | 0.66 | 0.60 | 3.39 |
| 2370 | 0.21 | 0.42 | 1.64 | 0.073 | 0.66 | 0.60 | 3.39 |
| 2340 | 0.26 | 0.39 | 1.64 | 0.073 | 0.66 | 0.60 | 3.39 |
| 2245 | 0.24 | 0.39 | 1.64 | 0.073 | 0.66 | 0.60 | 3.39 |
| 2200 | 0.16 | 0.36 | 1.64 | 0.073 | 0.66 | 0.60 | 3.39 |
| 2580 | 0.03 | 0.12 | 1.77 | 0.070 | 0.58 | 0.68 | 3.55 |
| 2350 | 0.05 | 0.13 | 1.77 | 0.070 | 0.58 | 0.68 | 3.55 |
| 2200 | 0.03 | 0.12 | 1.77 | 0.070 | 0.58 | 0.68 | 3.55 |
| 2565 | 0.03 | 0.11 | 1.68 | 0.069 | 0.63 | 0.68 | 3.57 |
| 2350 | 0.04 | 0.14 | 1.68 | 0.069 | 0.63 | 0.68 | 3.57 |
| 2200 | 0.03 | 0.13 | 1.68 | 0.069 | 0.63 | 0.68 | 3.57 |

variation due to pouring temperatures in this temperature range, however, was not of great magnitude. The chilling blocks were in all cases cold enough to be touched by the hand before a specimen was cast. Temperature readings on the metal were made with a Leeds & Northrup Optical Pyrometer and corrected for the surface condition of the metal. Each set was made from a single ladle of cast iron.

9. Different kinds of molding sand were used for ramming the chill test specimens. The results are given in Table 3. Sand

**Table 3**

EFFECT OF SAND ON DEPTH OF CHILL

| | Chill Depth— | | Sand Properties | | |
|---|---|---|---|---|---|
| | 1½ x 1½ x 6-in. Bar | | Compression | | Moisture— |
| Sand No. | First Gray | Last White | Strength—lbs. | Permeability | % |
| 1 | 0.02 | 0.12 | 7.5 | 650 | 5.6 |
| | 0.02 | 0.13 | | | |
| 2 | 0.02 | 0.13 | 5.0 | 358 | 6.8 |
| | 0.02 | 0.11 | | | |
| 3 | 0.02 | 0.13 | 12.5 | 341 | 6.5 |
| | 0.03 | 0.13 | | | |
| 4 | 0.02 | 0.10 blown | 12.0 | 67 | 9.0 |
| | blown out | | | | |

had little or no effect on the depth of chill, except in the case where permeability was so low and moisture so high that the test specimens were too badly blown to be of any value. All sets were from the same ladle of iron.

10. Miscellaneous defects in chill specimens, including deep chills due to blow holes or bad corners due to fins, and light chills due to slag or sand coming between the molten iron and the chill block, were easily detected when measuring the chill and were avoided.

## EFFECT OF COMPOSITION

*Silicon.*

11. Fig. 2 gives the effect of silicon on the depth of chill for cupola melted irons without special alloys or ladle additions. The results were grouped by total carbon content and the variations in other elements in each group are given on the graph. Copper, chromium and nickel contents were under 0.10 per cent each. Vanadium and molybdenum were kept under 0.05 per cent.

12. Silicon was found to be most effective in changing the depth of chill when the total carbon content was low. The variation of chill depth with silicon content was not linear, the lower silicon irons being more sensitive to increase in silicon content.

13. Fig. 3 shows six of the groups from Fig. 2 drawn on one scale to give the general effects of silicon content in irons of

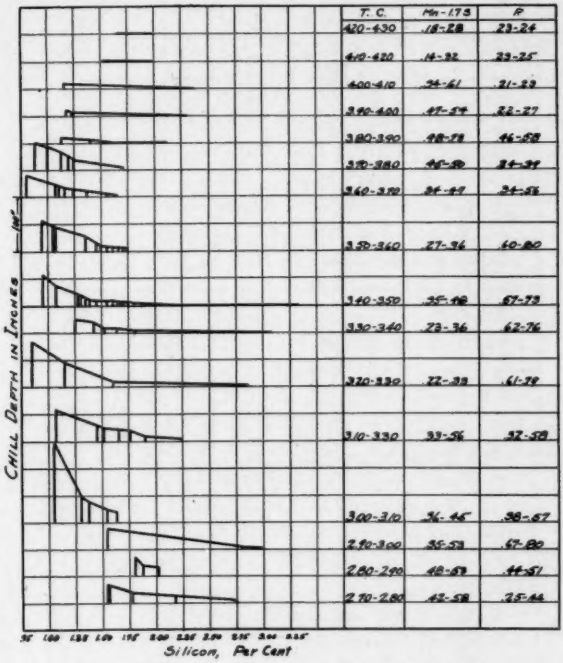
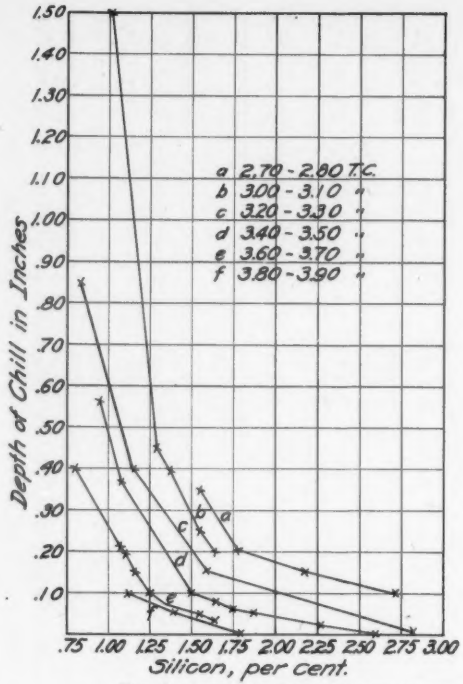



FIG. 2—EFFECT OF SILICON ON DEPTH OF CHILL.

different total carbon contents. It must be remembered that the manganese, sulphur, and phosphorus contents of these groups are not identical.

14. The breaking points and centers of rounded curves from Table 3 are shown plotted against silicon and total carbon in Fig. 4. These lines show where increasing silicon content tends to become less effective in decreasing the depth of chill in irons of different total carbon content. Phosphorus and actual manganese concentration minus 1.7 times the sulphur content are given for each set.



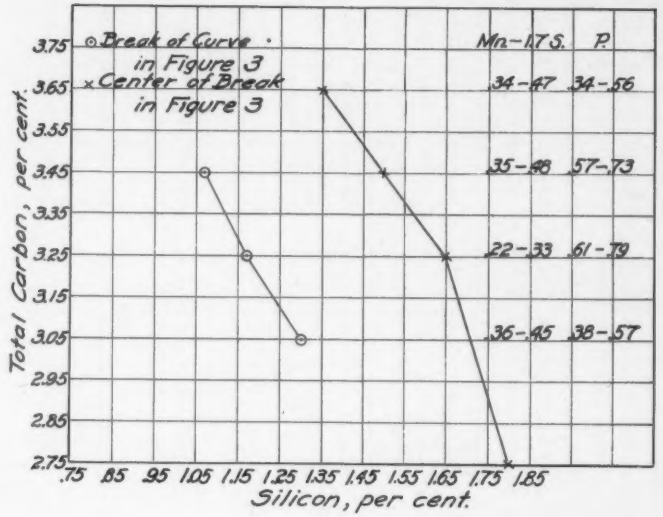




FIG. 3—LEFT—SILICON CONTENT SHOWN TO BE MOST EFFECTIVE WHEN TOTAL CARBON CONTENT IS LOW.
FIG. 4—RIGHT—MAXIMUM EFFECT OF SILICON AS RELATED TO DATA OF FIG. 3.

*Total Carbon.*

15. Fig. 5 gives the effect of total carbon on chill depth. The tests are grouped by silicon content and the other elements present are noted on the graph. Total carbon content had a relation to the chill depth similar to that of silicon.

*Phosphorus.*

16. Fig. 6 gives the depth of chill corresponding to various phosphorus contents when other elements were within comparable

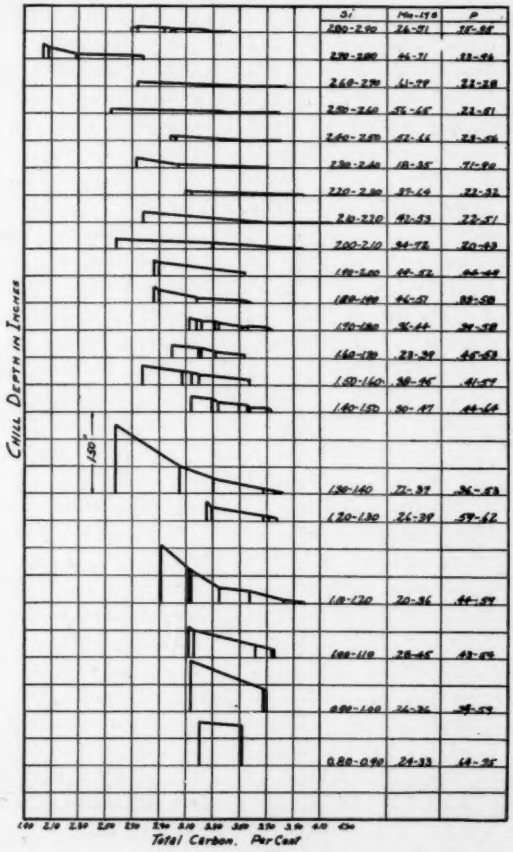



FIG. 5—EFFECT OF TOTAL CARBON ON CHILL DEPTH.

limits. Phosphorus tended to reduce chill depth, especially in irons having a great depth of chill.

*Manganese and Sulphur.*

17. Fig. 7 gives the depth of chill compared with the difference between the manganese content and 1.7 times the sulphur content in percentage. Manganese minus 1.7 times the sulphur was used because the ratio of manganese to sulphur in manganese

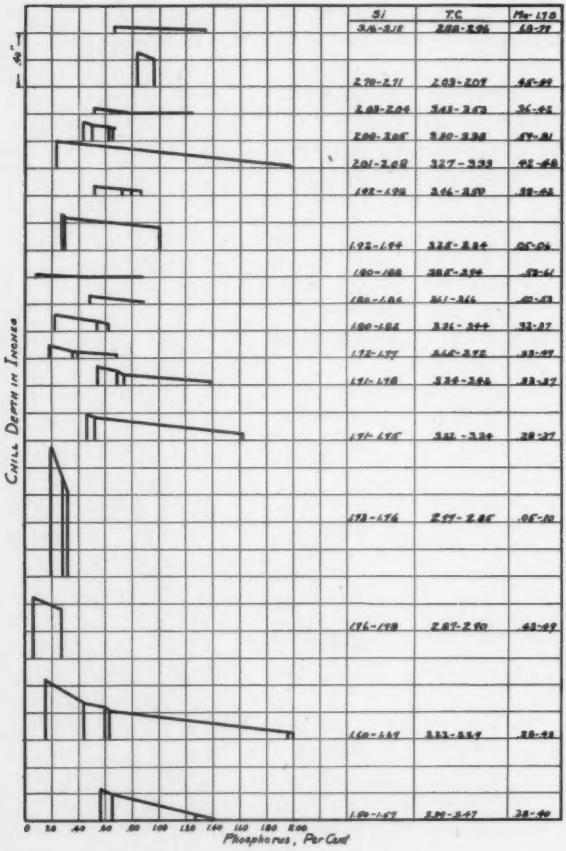



FIG. 6—EFFECT OF PHOSPHORUS ON CHILL DEPTH.

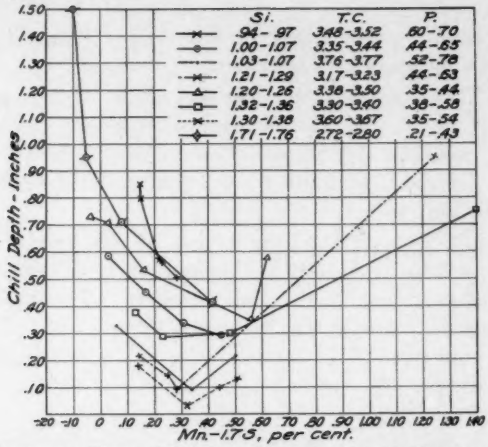



FIG. 7—MANGANESE MINUS 1.7 TIMES SULPHUR CONTENT EFFECT ON CHILL.

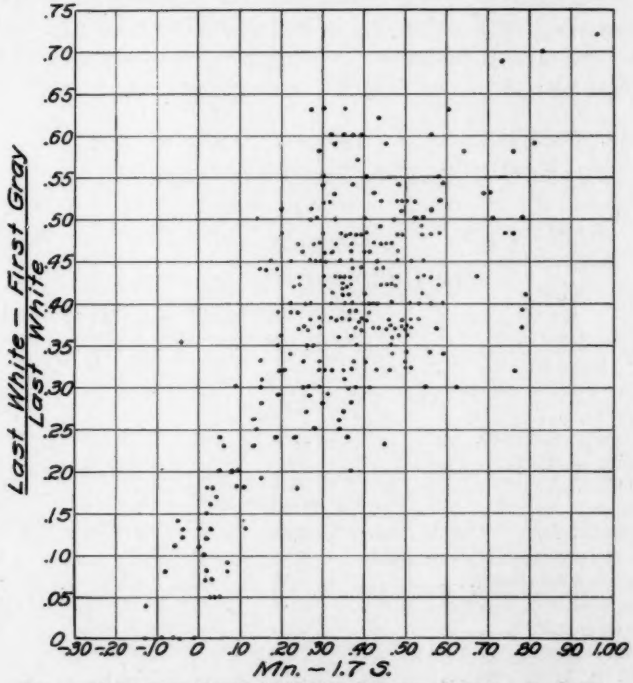



FIG. 8—MANGANESE MINUS 1.7 TIMES SULPHUR CONTENT AND RATIO $\frac{\text{LAST WHITE—FIRST GRAY}}{\text{LAST WHITE}}$

sulphide was 1.7, approximately. The groups in the diagram represent different classes of cast irons.

18. Where the sulphur was in excess of the amount required for the formation of manganese sulphide, the chill depth increased rapidly. Manganese in excess, up to about 0.30 to 0.35 per cent, decreased the chill. Over that amount, manganese increased the chill depth.

19. Fig. 8 gives the comparison of manganese minus 1.7 times the sulphur and the distinctness of demarcation between chilled and gray iron in the chill specimen. The distinctness of the demarcation of chill was measured by the ratio of last white minus first gray, divided by last white on chill specimens. In other words, the ratio of indefinite portion of chill to total chill was used.

20. A distinct line of demarcation, where first gray and last white corresponded, was associated with high sulphur and low manganese. This series of tests included chills from 0.10 to 1.00 ins., first gray measurement, on $1\frac{1}{2} \times 1\frac{1}{2}$ in. specimens. Phosphorus content ranged from 0.03 to 1.98 per cent.

*Other Additions.*

21. Table 4 gives the effects of various additions on the

**Table 4**

MISCELLANEOUS LADLE ADDITIONS

| Additions | Added element in sample—per cent | Chill Depth With Addition | Chill Depth Plain |
|---|---|---|---|
| Aluminum | 1.74 | 0.08 | 0.72 |
| Aluminum, 1 per cent | .... | 0.10 | 0.37 |
| Arsenic | 0.34 | 0.10 | 0.19 |
| Boron, 1 per cent | .... | 0.16 | 0.37 |
| Cobalt | 0.17 | 0.36 | 0.19 |
| Cobalt | 0.08 | 0.27 | 0.19 |
| Copper | 1.35 | 0.02 | 0.05 |
| Copper | 2.91 | 0.17 | 0.19 |
| Ferromolybdenum | 0.39 | 0.25 | 0.25 |
| Ferromolybdenum | 0.54 | 0.40 | 0.39 |
| Ferrotitanium, 1 per cent | 0.09 | 0.32 | 0.37 |
| Ferrotungsten | 0.25 | 0.20 | 0.19 |
| Ferrovanadium | 0.31 | 0.93 | 0.37 |
| Cerium, 1 per cent | .... | 1.15 | |
| Magnesium, 1 per cent | .... | 0.40 | One Ladle |
| Ferroboron, 1 per cent | .... | 0.10 | |

**Table 5**

MISCELLANEOUS LADLE ADDITIONS

| Increase Chill | Decrease Chill | Very Little Effect |
|---|---|---|
| Antimony | Aluminum | |
| Bismuth | Arsenic | Copper |
| Brass | Boron | |
| Cadmium | Titanium | Tungsten |
| Cerium | | Molybdenum |
| Cobalt | | |
| Chromium | | |
| Lead | | |
| Magnesium | | |
| Tin | | |
| Tungsten | | |
| Vanadium | | |

chill depth of cast iron. The results are summarized in Table 5. in which are included various additions reported in a previous paper.[1] Nickel and chromium are not included because the results checked previous published works of other authors on these two additions.

RELATION OF COMBINED CARBON AND CHILL DEPTH

22. The test bar, 2 x 1 x 26 ins., cast in a dry sand mold, was analyzed for graphitic and total carbon, and the depth to the first gray on the 1½ x 1½ x 6 in. chill specimen cast with the test bar was compared with the ratio of graphitic carbon to total carbon as found in the test bar. Approximately 650 tests of cupola-melted, non-alloyed irons were included in this study. The graph gave a series of points with a decided trend to the straight line:

$$y + 3x = 2.4$$

Where $y$ was depth of chill to first gray on 1½ x 1½ in. specimens, and $x$ was the ratio of graphitic carbon to total carbon on 1 x 2 x 26 in. dry sand cast bars.

23. One hundred and thirty-seven tests which had less chill depth, or less graphitic carbon in the test bar than necessary to place them on or near the line were examined with the following results:

In 101, manganese minus 1.7 times the sulphur was less than

[1] Spencer, W. H., and Walding, M. M., "Effects of Eleven Metals or Alloys on the Physical Properties of Gray Cast Iron," Trans. A.F.A., vol. 40, p. 491 (1932).

0.35 per cent, 13 had total carbon under 2.50 per cent. 11 had silicon over 2.75 per cent and total carbon 2.50 to 3.02 per cent. 6 had no apparent reason.

24. Forty-three tests which had more chill depth or more graphitic carbon in the test bars than necessary to place them on or near the line gave the following results:

14 had silicon less than 1.25 per cent.

24 had manganese minus 1.7 times the sulphur content greater than 0.50 per cent.

5 had no apparent reason.

25. The study of points off the line, indicated that slow cooling, as in the test bars, gave higher graphitic and lower combined carbon than indicated by the faster cooled chills either when the manganese was high as compared to the sulphur or when the silicon was low. The reverse was true when the sulphur was high as compared to manganese, or when the total carbon was low.

## PRACTICAL APPLICATION OF CHILL TESTS

26. The American Cast Iron Pipe Co. uses the chill test as a rapid control method of the melting operation. Chill specimens are cast every half hour in cast iron molds. The depth and nature of the chill and the gray background are observed to check the mixture and melting conditions. The depth of chill is recorded for each test. Depth of chill is taken as the average of the depths to the first gray and last white portions of the fractures for shop purposes. Measurements are made with a rule divided into sixteenths of an in. and approximated between divisions.

27. Shop measurements on 141 chills of irons between 1.50 and 1.60 per cent silicon, 0.080 and 0.090 per cent sulphur, 0.45 and 0.55 per cent manganese, 0.60 and 0.70 per cent phosphorus, and 3.50 to 3.60 per cent total carbon were arranged statistically. Cell groups were centered 1/32 in. apart in chill measurements. The number of cells, $n$, was 7, ranging from 0 through 3/16 in. chill depth. The average chill depth, X, was 0.0807 in. Standard deviation, $\delta$, was 0.0192 in. In other words, over 75 per cent of the chill measurements were between .04 in. and 0.12 in., $X \pm 2\,\delta$.

28. Since the shop measurements were averages of first gray and last white portions of the fracture, the exact measure-

ments were made on seven samples to determine the maximum and minimum readings possible on a chill from this iron. The averages obtained were 0.067 in. for first gray and 0.11 in. for last white portions of the fracture. These figures were in fair agreement with the 0.04 in. and 0.12 in. obtained by the system of average measurement in the shop, where the depth of chill was left to the judgment of the man making the measurement. Some measurements would be to the first gray portion, and some to last white portion. For best results it was necessary to make

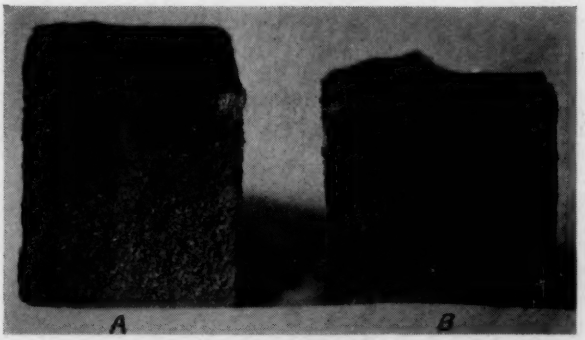



FIG. 9—TWO TESTS WITH WIDELY DIFFERING SILICON—TOTAL CARBON RATIOS HAVING APPROXIMATELY SAME CHILL DEPTH.

two sets of readings on each chill, one to the first gray portion and the other to the last white portion of the fracture.

## APPEARANCE OF FRACTURE OF CHILL TEST SPECIMEN

29. The appearance of the chilled and gray portions of the chill test specimen was important. Two ratios gave distinctive appearance to the fracture.

30. *Silicon—Total Carbon Ratio.* Two chill tests, having widely different silicon-total carbon ratios, had approximately the same depth of chill. Fig. 9 is a photograph of two chill tests having the following composition:

| Test | Si.— % | S.— % | Mn.— % | P.— % | T.C.— % | Chill depth— in. to first gray |
|---|---|---|---|---|---|---|
| A | 1.18 | 0.039 | 0.35 | 0.56 | 3.84 | 0.06 |
| B | 3.20 | 0.071 | 0.91 | 0.67 | 2.96 | 0.04 |

31. In this case, the gray structure made differentiation possible. The high carbon, low silicon iron had very coarse gra-

phite, and the low carbon, high silicon iron had a fine grained, slaty appearance.

32. *Manganese-Sulphur Ratio.* Fig. 10 shows two chill tests having different manganese-sulphur ratios. The analyses of the two specimens were as follows:

| Test | Si.— % | S.— % | Mn.— % | P.— % | T.C.— % |
|---|---|---|---|---|---|
| C | 1.50 | 0.094 | 0.94 | 0.52 | 3.19 |
| D | 1.53 | 0.221 | 0.30 | 0.50 | 3.30 |

33. These showed clearly the sharp demarcation of the high sulphur chill and the irregular chill of the high manganese specimen.

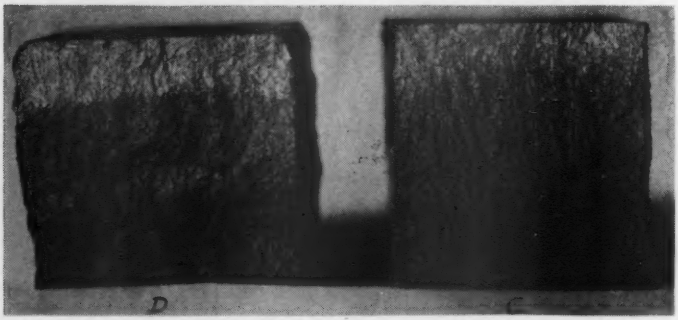



FIG. 10—TWO CHILL TESTS WITH DIFFERENT MANGANESE-SULPHUR RATIOS.

## SUMMARY

34. The results of the tests may be summarized as follows:

(1) *Silicon*—Increasing silicon content reduced chill in cast iron, being more effective where silicon or total carbon was low.

(2) *Total Carbon*—Increasing total carbon content reduced depth of chill.

(3) *Phosphorus*—Increasing phosphorus content reduced the depth of chill, especially in deep chilling irons.

(4) *Sulphur and Manganese*—High sulphur or high manganese content increased depth of chill. Minimum chill occurred when manganese minus 1.7 times the sulphur was approximately 0.35 per cent.

(5) *Sulphur-Manganese Ratio*—High sulphur to manganese ratio gave distinct line of demarcation between chilled and gray portions of the specimen.

(6) *Ladle Additions*—Antimony, bismuth, brass, cadmium, cobalt, lead, tin, and vanadium, as ladle additions, increased the depth of chill.

(7) Aluminum and boron as ladle additions, reduced the depth of chill.

(8) The ratio of graphitic carbon to total carbon on sand cast test bars gave comparable results with the depth of chill on test specimens, except that high sulphur irons were harder in sand cast bars than the chill test indicated, and high manganese or low silicon irons were softer in the sand cast bars than the chill test indicated.

(9) The ratio of silicon to total carbon and of manganese to sulphur were qualitatively indicated by the chill test.

(10) The chill test specimen, as used, could be applied to shop control of the mixture and melting operation.

ACKNOWLEDGMENT

35. The author wishes to acknowledge the assistance of the American Cast Iron Pipe Co., Dr. J. T. MacKenzie, H. Johnson, R. H. Elder, and R. E. Deas in the preparation of the material for this paper.

## DISCUSSION

F. J. WALLS[1]: I would like to ask Mr. Spencer a few questions with respect to the pouring temperature of the iron against that chill, and how he controls the temperature of the chill box itself. We have found that the pouring temperature of the iron against the chill has more influence than the chemical analysis of the metal itself.

MR. SPENCER: The measuring of the temperature of the chill block was done by placing the hand on it. Table No. 2 shows the effect of pouring temperature on the depth of chill.

These figures indicate slightly varied chilling on hotter pouring, which is contrary to what has previously been published by several authors. I took another ladle into a wider range of temperature, from 2633 degrees Fahr. down to 2200 degrees Fahr., same grade of iron, and these figures were as given in Table 3.

Very hot pouring gave a light chill; very cold pouring gave the heaviest chill; the variation was approximately two hundredths of an inch, due to difference in pouring temperature. Selecting a pouring temperature and pouring close to that temperature is the only recommendation that I can give to avoid these variations. Another point I would like to mention is the method of pouring. Do not pour the hot iron against the chill mold. Fins give false chilling.

[1] Eaton-Erb Foundry Co., Detroit, Mich.

MR. WALLS: What are the dimensions of that chill block?

MR. SPENCER: The dimensions of the chill block are 1½x1½x6 ins.

MR. WALLS: The block?

MR. SPENCER: The actual chilling portion of the chill block is 3 ins. thick, 6 ins. wide, 12 ins. across, with an L shaped base; 2x6¼x12 ins.

MEMBER: In any of the tests, was silicon added to the ladle?

MR. SPENCER: All of these tests were made on non-alloy irons; in other words, no silicon being added in the ladle. We did not have complete information as to the anomalous effect of adding silicon to the ladle; we only used results in which the silicon was melted in the furnace.

MR. WALLS: My interpretation of Mr. Spencer's conclusion is that the sulphur-manganese ratio controls that line of demarcation between chill and gray iron and that if a ratio is not in proper balance, you get more or less the mottled effect between the white and gray iron. Is that correct? Is it your conclusion that the sulphur-manganese balance controls the mottled and straight line effect?

MR. SPENCER: Except that I would not refer to it as a mottled effect. The one we referred to was the chill with "whiskers" on it, is not a mottling. It is like a wire lacing the gray and the white together. When that feature is absent, the line of demarcation is very distinct, as with the high sulphur. The one you have reference to, is a mottling or white plate and I did not give any particular reason for the mottling. It was the "whiskers" to which I referred.

MR. WALLS: Could you give the reason for that "whiskers" effect?

MR. SPENCER: I did not cover that question in this work. I merely presented results and left them for the interpretation of others.

# Fatigue Tests of High Strength Cast Irons

By H. F. Moore* and J. J. Picco**, Urbana, Ill.

**Abstract**

*The authors tested four different irons, one of which was used both in the "as cast" and the heat treated condition. The tests included static tension tests, static compression tests, fatigue tests under cycles of completely reversed flexure, fatigue tests in flexure varying from zero to a maximum stress in one direction, fatigue tests under cycles of completely reversed torsion, and fatigue tests in torsion varying from zero to a maximum stress in one direction. Brinell hardness tests were also made.*

*The specimens for the different tests, and the machines and apparatus, are described and illustrated. The results are given both in tabular and in graphical form. In general, they indicate that the fatigue strength of the irons tested is approximately proportional to the static tensile strength of the irons.*

1. *Object of Tests.* Data on the fatigue strength of high-test cast irons are rather few, and it is believed that the data presented in this paper may be of some value. Four different irons were tested, including one iron tested both in the "as cast" condition and after heat treatment. The tests included static tension tests, static compression tests, fatigue tests in flexure varying from zero to a maximum stress in one direction, fatigue tests under cycles of completely reversed flexure, fatigue tests in torsion varying from zero to a maximum stress in one direction, and fatigue tests under cycles of completely reversed torsion. Brinell hardness tests were also made.

* Research Professor of Engineering Materials, University of Illinois.

** Graduate Student in Chemistry, University of Illinois.

Note: This paper was presented at the joint A.S.T.M.-A.F.A. meeting on Testing Cast Iron held at the 1934 Convention of A.F.A.

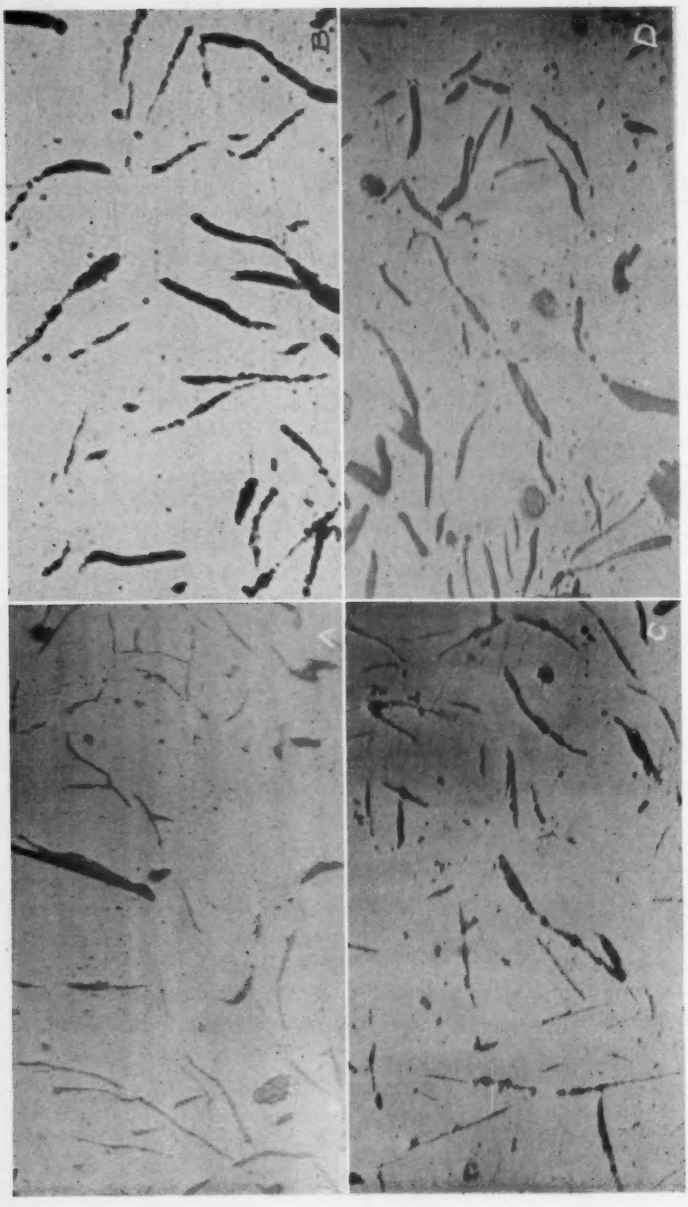



FIG. 1—MICROSTRUCTURES OF IRONS TESTED. MAGNIFICATION 150X. UNETCHED.

2. The chemical analyses of the irons tested were furnished by the foundries where the irons were cast, and they are given in Table 1. Irons "A", "C", and "D" were tested "as cast". Iron "B" was tested "as cast", as iron "B'" is the same iron given the following heat treatment: Heat slowly to 1000 deg. Fahr., then heat quickly to 1600 deg. Fahr., quench in oil, then draw at 1000 deg. Fahr.

3. The crystalline structures of the irons tested are shown in the micrographs, Figs. 1, 2A and 2B.

**Table 1**

CHEMICAL COMPOSITION OF IRONS TESTED

| Iron | Chemical Content — per cent | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Total Carbon | Combined Carbon | Silicon | Manganese | Nickel | Sulphur | Phosphorus | Molybdenum |
| A | 3.09 | .... | 2.01 | 0.60 | .... | 0.08 | 0.16 | 0.65 |
| B & B'* | 3.07 | .... | 1.26 | 0.90 | .... | 0.08 | 0.15 | .... |
| C | 3.18 | 0.83 | 1.34 | 0.89 | .... | 0.09 | 0.11 | .... |
| D | 2.91 | .... | 2.28 | 0.85 | 0.88 | 0.10 | .... | .... |

* All irons except B[1] were tested "as cast." Iron B was tested "as cast," but Iron B[1] was pre-heated slowly to 1000 deg. Fahr., then heated quickly to 1600 deg. Fahr., then quenched in oil and drawn at 1000 deg. Fahr.

4. Fig. 3 shows the various test specimens used. Fig. 3 (a) shows the specimen for static tension tests; it is a specimen which has proved very satisfactory in the University of Illinois Materials Testing Laboratories for tests of brittle metals. It is held by the shouldered ends in split chucks, and the bearing blocks on the testing machine heads are fitted with spherical seats.

5. Fig. 3 (b) shows the specimen for static compression tests. The compression specimens were first machined to a length of 2.10 inches and used to determine yield strength, then the specimen was removed from the testing machine, machined to a length of 1.40 inches and tested to fracture. A specimen 3 diameters long is suitable for determining yield strength, but it is not satisfactory for determining compression strength because of its tendency to buckle under a load to fracture.[1] The ends of the compression specimens were very carefully machined plane and parallel.

6. Fig. 4 shows the rig used for the static compression tests.

7. The Brinell tests were made on an Alpha machine using a 10 mm. ball and a 3000 kg. load.

8. Fig. 3 (c) shows the specimen used for fatigue tests in torsion, and Fig. 3 (d) shows the specimen used for fatigue tests in flexure.

9. The static tension tests were made on an Amsler 100,000-lb. testing machine, and the static compression tests to determine

[1] Proceedings, American Society for Testing Materials, V. 33, Part I, pp. 90-91, 1933.

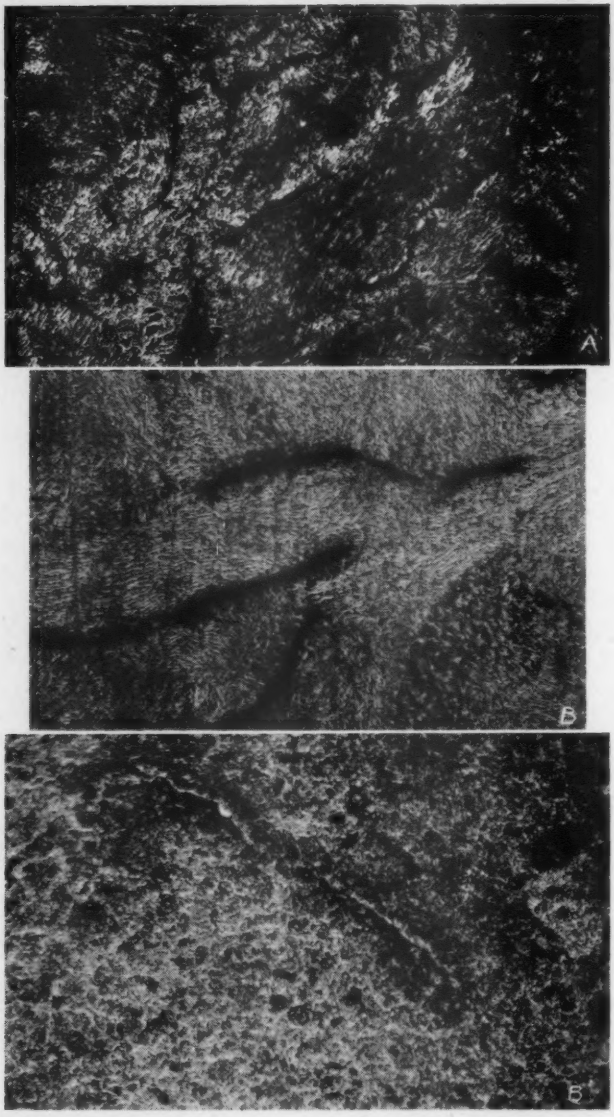



FIG. 2A—MICROSTRUCTURES OF IRONS A, B AND B' TESTED. MAGNIFICATION 500X ETCHED IN 5 PER CENT NITAL.

yield strength were made on a 60,000-lb. Emery-Southwark testing machine fitted with a hydraulic support and Bourdon gages for weighing the load. The static compressive tests to destruction were made on a 100,000-lb. Olsen screw-power machine with beam balance for weighing the load.

10. For obtaining data for plotting stress-strain diagrams a 2-inch Olsen extensometer was used, and for the compression tests a special 1-inch compressometer fitted with a "Last Word" micrometer dial reading to 0.0001 inch was used.

11. The fatigue tests in torsion were made on a special torsion fatigue testing machine designed and built in the Materials Testing Laboratory shop, and the fatigue tests in flexure were

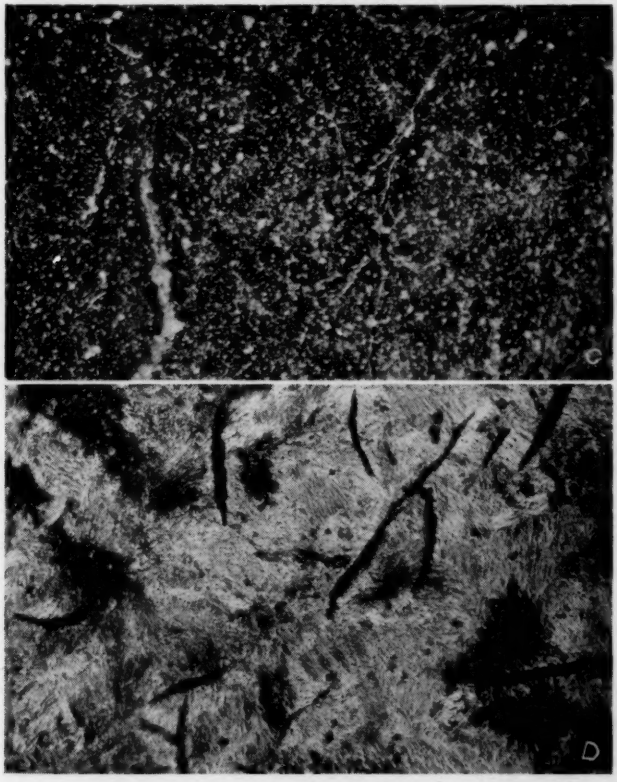



Fig. 2B—Microstructure of Irons C and D. Magnification 500X. Etched in 5 Per Cent Nital.

made on a special flexure attachment for this torsion fatigue testing machine.[2]

11a. The cast iron in all cases except iron *"D"* was supplied in the form of hollow cylinders approximately 7 inches outside diameter and with a wall thickness varying from 1 to 1¼ ins. From these cylinders, longitudinal strips were milled from which specimens were machined. The iron *"D"* was submitted in the form of a cylinder with a rib on it. The specimens were not cut from the rib.

## RESULTS OF STATIC TENSION AND STATIC COMPRESSION TESTS

12. In tests of cast iron the question of what value shall be used for a criterion of elastic strength is a rather puzzling one.

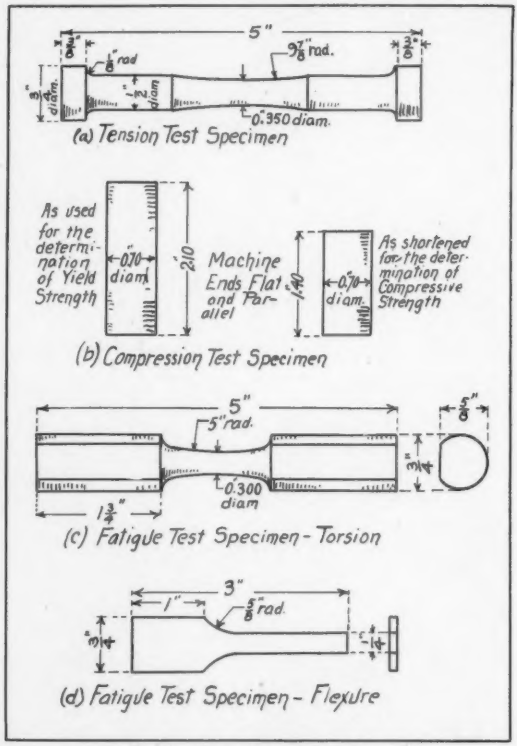



FIG. 3—TEST SPECIMENS USED.

[2] A detailed description of this machine and of the flexible attachment is given in Circular 23 of the University of Illinois Engineering Experiment Station.

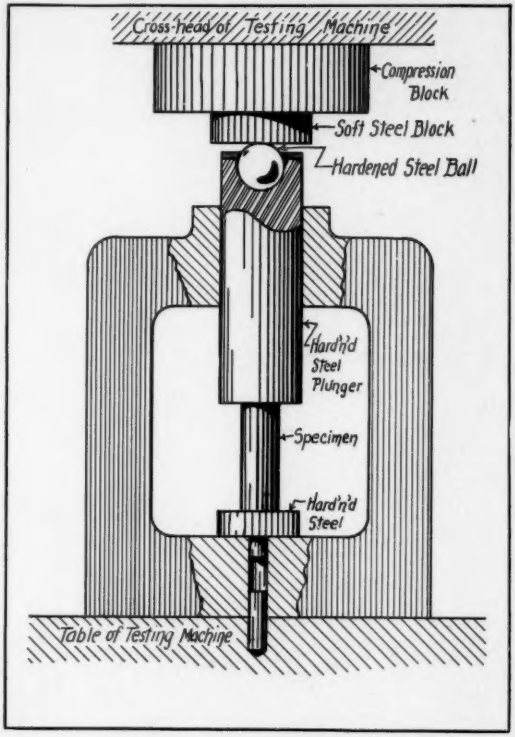



Fig. 4—Compression Rig.

Cast iron has no clearly defined yield point, and its stress-strain diagram seems slightly, but appreciably curved from the very origin.[3] For this report it has been decided to adopt as a criterion of elastic strength the "yield strength" determined by the "set" method described in the 1933 Tentative Standards of the American Society for Testing Materials, pp. 1059-1061.[4] The limiting "approximate sets" used was 0.1 per cent of the gage length, and the method of determining yield strength can be seen in the stress-strain diagrams shown in Fig. 5.

13. The tensile strength and the compressive strength were determined in the usual manner. Table 2 gives the average results

[3] This is probably true for all metals, although in many of the rolled or forged metals this deviation is too slight to be detected, even with the most delicate instruments available.

[4] A fuller description of this method is given in the Appendix to this paper.

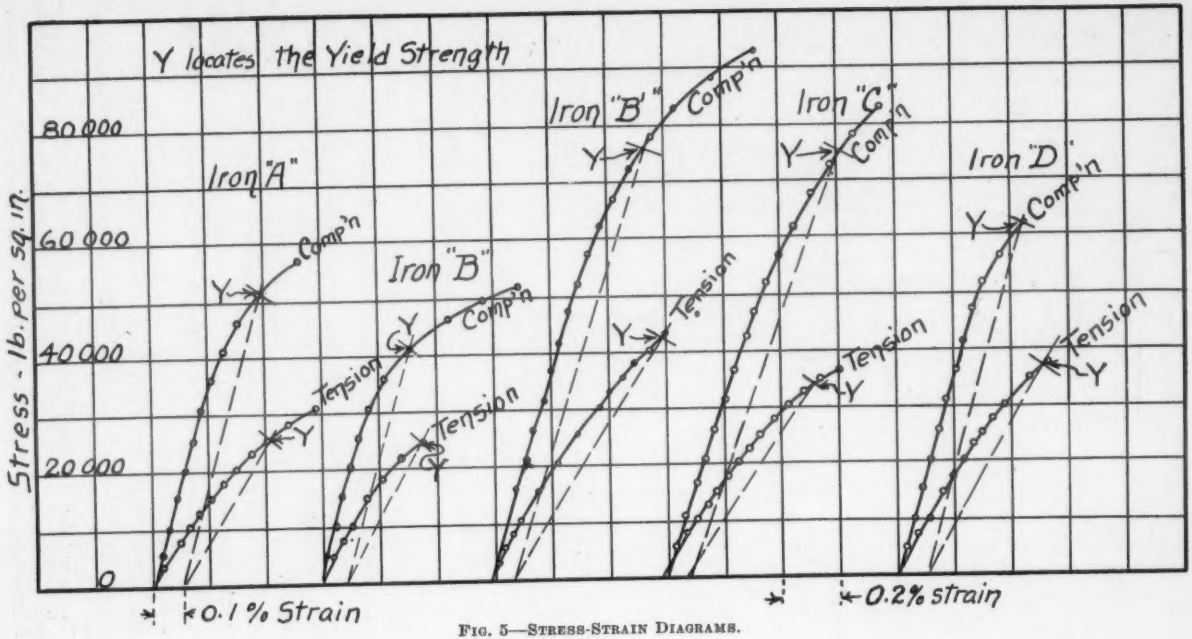



FIG. 5—STRESS-STRAIN DIAGRAMS.

of the static strength tests, and Fig. 5 shows typical stress-strain diagrams.

## Results of Fatigue Tests

14. Table 3 gives the data of the fatigue tests carried out, and the endurance limits can be determined directly from the table. A fatigue specimen was considered to have reached the endurance limit when it had withstood 10,000,000 cycles of stress without fracture, although in one case, (metal "A" under cycles of torsion varying from zero to a maximum in one direction), one specimen "ran out" to 10,000,000 cycles under a stress which was

**Table 2**

Static Strength Values of Irons Tested

| Iron | In Tension | | In Compression | | Brinell Number (3000 Kg Load) |
|---|---|---|---|---|---|
| | Yield Strength (set=0.1%) | Tensile Strength | Yield Strength (set=0.1%) | Compressive Strength | |
| | lbs. per sq. in. | | | | |
| A | 25,200 | 44,000 | 52,000 | 120,000 | 217 |
| B* | 25,000 | 48,000 | 41,700 | 147,000 | 187 |
| B'* | 41,800 | 76,500 | 76,000 | 183,000 | 255 |
| C | 33,400 | 55,000 | 75,500 | 159,200 | 255 |
| D | 37,000 | 56,500 | 62,200 | 173,7 0 | 241 |

*B' is metal B heat-treated. See footnote to Table 1.

evidently above the endurance limit for the other specimens. Table 4 gives the endurance limits determined for the different irons.

15. Under torsional stress a brittle material like cast iron fails not in shear, but under diagonal tension as shown in Fig. 6. The maximum diagonal tension stress (lb. per sq. in.) is equal to the maximum shearing stress[5] under torsion. It would seem, then,

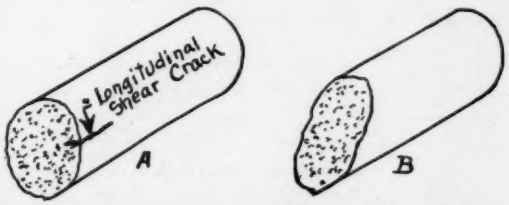



Fig. 6—Torsion Fractures of Metal. (A) Torsion Fracture of a Ductile Metal. Failure Due to Transverse Shearing Stress, With a Crack Indicating the Beginning of a Failure Due to Longitudinal Shearing Stress. (B) Torsion Fracture of a Brittle Metal. Failure Due to Tensile Stress on Inclined Plane. All the Cast Iron Specimens Tested in Torsion Showed This Type of Fracture.

[5] For proof of this see Seely—"Advanced Mechanics of Materials", p. 23, John Wiley and Son, New York. It is also to be noted that the transverse shearing stress under torsion is the same in magnitude at the longitudinal.

## Table 3

### DATA OF FATIGUE (REPEATED STRESS) TESTS OF HIGH-TEST CAST IRONS

| Iron | Type of Stress | Range of Stress | Maximum Computed Stress in lb. per sq. in. | Number of Cycles for Fracture |
|---|---|---|---|---|
| A | Flexure | Zero to maximum | 26,000 | 184,000 |
| | | | 25,000 | 466,000 |
| | | | 24,000 | 958,000 |
| | | | 23,000 | 10,000,000* |
| | | Endurance Limit: | 23,000 lb. per sq. in. | |
| A | Flexure | Complete reversal | 25,000 | 69,600 |
| | | | 22,000 | 1,512,000 |
| | | | 21,000 | 298,000 |
| | | | 20,000 | 253,500 |
| | | | 19,000 | 10,000,000* |
| | | | 18,000 | 10,000,000* |
| | | Endurance Limit: | 19,000 lb. per sq. in. | |
| A | Torsion | Zero to maximum | 27,000 | 165,000 |
| | | | 26,000 | 10,000,000* |
| | | | 25,000 | 116,100 |
| | | | 24,000 | 853,000 |
| | | | 23,000 | 10,000,000* |
| | | Endurance Limit: | 23,000 lb. per sq. in. | |
| A | Torsion | Complete reversal | 19,000 | 47,300 |
| | | | 18,000 | 133,500 |
| | | | 17,000 | 500,000 |
| | | | 16,000 | 10,000,000* |
| | | Endurance Limit: | 16,000 lbs. per sq. in. | |
| B | Flexure | Zero to maximum | 34,000 | 235,000 |
| | | | 33,000 | 240,000 |
| | | | 32,000 | 10,000,000* |
| | | | 30,000 | 10,000,000* |
| | | | 28,000 | 1,200,000 |
| | | | 27,000 | 10,000,000* |
| | | | 26,000 | 10,000,000* |
| | | Endurance Limit: | 32,000 lb. per sq. in. | |
| B | Flexure | Complete reversal | 24,000 | 175,000 |
| | | | 22,000 | 320,000 |
| | | | 21,000 | 10,000,000* |
| | | Endurance Limit: | 21,000 lb. per sq. in. | |
| B | Torsion | Zero to maximum | 27,000 | 725,000 |
| | | | 26,000 | 210,000 |
| | | | 25,000 | 10,000,000* |
| | | Endurance Limit: | 25,000 lb. per sq. in. | |
| B | Torsion | Complete reversal | 19,000 | 250,000 |
| | | | 18,000 | 1,080,000 |
| | | | 17,000 | 6,484,000* |
| | | | 16,500 | 10,000,000 |
| | | Endurance Limit: | 16,500 lb. per sq. in. | |
| B′ | Flexure | Zero to maximum | 42,000 | |
| | | | 39,000 | |
| | | | 38,000 | |
| | | Endurance Limit: | 28,000 lb. per sq. in. | |
| B′ | Flexure | Complete reversal | 34,000 | 27,800 |
| | | | 33,000 | 67,600 |
| | | | 30,000 | 129,900 |
| | | | 28,000 | 77,000 |
| | | | 26,000 | 170,000 |
| | | | 25,000 | 10,000,000* |
| | | Endurance Limit: | 25,000 lb. per sq. in. | |
| B′ | Torsion | Zero to maximum | 39,000 | 60,100 |
| | | | 38,000 | 89,700 |
| | | | 37,000 | 122,300 |
| | | | 36,000 | 100,100 |
| | | | 35,000 | 112,700 |
| | | | 34,000 | 171,000 |
| | | | 33,000 | 140,000 |
| | | | 32,000 | 350,000 |
| | | | 31,000 | 250,000 |
| | | | 29,000 | 10,000,000* |
| | | Endurance Limit: | 29,000 lb. per sq. in. | |

*Did not fracture.

(Continued on next page)

**Table 3—Continued**

Data of Fatigue (Repeated Stress) Tests of High-Test Cast Irons

| Iron | Type of Stress | Range of Stress | Maximum Computed Stress Cycles lb. per sq. in. | Number of Cycles for Fracture |
|---|---|---|---|---|
| B′ | Torsion | Complete reversal | 24,000 | 202,500 |
| | | | 23,000 | 300,300 |
| | | | 22,000 | 10,000,000* |
| C | Flexure | Zero to maximum | 34,000 | 20,000 |
| | | | 30,000 | 205,000 |
| | | | 29,000 | 335,000 |
| | | | 28,000 | 1,800,000 |
| | | | 27,000 | 10,000,000* |
| | | Endurance Limit: | 27,000 lb. per sq. in. | |
| C | Flexure | Complete reversal | 24,000 | 240,000 |
| | | | 23,000 | 93,000 |
| | | | 22,000 | 10,000,000* |
| | | Endurance Limit: | 22,000 lb. per sq. in. | |
| C | Torsion | Zero to maximum | 34,000 | 51,000 |
| | | | 32,000 | 80,000 |
| | | | 29,000 | 310,000 |
| | | | 28,000 | 215,000 |
| | | | 27,000 | 180,000 |
| | | | 26,000 | 10,000,000* |
| | | Endurance Limit: | 26,000 lb. per sq. in. | |
| C | Torsion | Complete reversal | 23,000 | 64,000 |
| | | | 22,000 | 155,000 |
| | | | 21,000 | 10,000,000* |
| | | Endurance Limit: | 21,000 lb. per sq. in. | |
| D | Flexure | Zero to maximum | 40,000 | 77,900 |
| | | | 36,400 | 91,000 |
| | | | 34,000 | 82,000 |
| | | | 33,000 | 10,000,000* |
| | | Endurance Limit: | 33,000 lb. per sq. in. | |
| D | Flexure | Complete reversal | 47,000 | 1,500 |
| | | | 35,000 | 16,100 |
| | | | 25,200 | 160,500 |
| | | | 24,500 | 427,900 |
| | | | 22,000 | 10,000,000* |
| | | Endurance Limit: | 22,000 lb. per sq. in. | |
| D | Torsion | Zero to maximum | 36,000 | 171,000 |
| | | | 34,000 | 955,000 |
| | | | 33,000 | 10,000,000* |
| | | Endurance Limit: | 33,000 lb. per sq. in. | |
| D | Torsion | Complete reversal | 30,000 | 11,200 |
| | | | 24,000 | 12,400 |
| | | | 21,000 | 107,000 |
| | | | 20,500 | 140,500 |
| | | | 20,000 | 10,000,000* |
| | | Endurance Limit: | 20,000 lb. per sq. in. | |

*Did not fracture.

**Table 4**

Endurance Limits (Fatigue Strengths) for Irons Tested

| Iron | Endurance Limit—lb. per sq. in. | | | | Ratios | | | |
|---|---|---|---|---|---|---|---|---|
| | Flexure | | Torsion | | (2): Tensile Strength (static) | (2):(4) | (1):(2) | (3):(4) |
| | Stress Range 0 to max. (1) | Complete Reversal of Stress (2) | Stress Range 0 to max. (3) | Complete Reversal of Stress (4) | | | | |
| A | 23,000 | 19,000 | 23,000 | 16,000 | 0.43 | 1.19 | 1.21 | 1.44 |
| B* | 32,000 | 21,000 | 25,000 | 16,500 | 0.44 | 1.27 | 1.52 | 1.51 |
| B′* | 38,000 | 25,000 | 29,000 | 22,000 | 0.33 | 1.14 | 1.52 | 1.32 |
| C | 27,000 | 22,000 | 26,000 | 21,000 | 0.40 | 1.05 | 1.23 | 1.24 |
| D | 33,000 | 22,000 | 33,000 | 20,000 | 0.39 | 1.10 | 1.50 | 1.65 |

*Iron B′ is iron B heat-treated. See footnote to Table 1.

since in both flexure and torsion tests the failure is a tension failure, that the endurance limit should be about the same. Except for metal "B" this seems to be the case.

16. In Table 4 are also shown various ratios. The ratio (endurance limit for completely reversed flexure) : (endurance limit for flexure varying from zero to a maximum in one direction) ranges from 1.21 to 1.52; and the ratio (endurance limit for completely reversed torsion) : (endurance limit for torsion varying from zero to a maximum in one direction) ranges from 1.24 to 1.65. The ratio (endurance limit for completely reversed flexure) : (static tensile strength) ranges from 0.33 to 0.44, being somewhat lower than the ratio usually found for rolled steel.

17. In general, the results of the tests reported in this paper indicate that the fatigue strength of the irons tested is approximately proportional to the static tensile strength of the irons.

### ACKNOWLEDGMENT

18. The tests reported in this paper were made in the Materials Testing Laboratory of the University of Illinois. The work was carried out by Mr. Picco as a problem in a graduate course in Advanced Materials Testing, under the immediate direction of Professor H. F. Moore, and as a part of the work of the Department of Theoretical and Applied Mechanics, of which Professor F. B. Seely is head.

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## APPENDIX

### DETERMINATION OF YIELD STRENGTH

19. The following quotations from the 1933 Tentative Standards of the American Society for Testing Materials describe a method used in determining "yield strength." It may be added that this method has been in use in Germany for some time.

> "*Yield Strength*—The stress at which a material exhibits a specified limiting permanent set.
>
> NOTE.—It is usually impracticable and probably impossible to determine the stress at which inelastic action in a member begins. Plastic yielding in nearly all members (including the specimen in a carefully controlled laboratory test) starts as local actions and becomes measureable only after many local internal adjustments and accommodations have occurred, and

after a considerable portion of the member is affected by the yielding."

"The limit of usefulness of many materials, especially metals, in members subjected to approximately static loading at ordinary temperatures is therefore determined by a measurable value of plastic yielding of the material above which the material is considered to be damaged and below which the damaging effects are considered to be negligible."

20. Several methods for determining yeild strength are given in the Tentative Specifications. The method which applies to cast

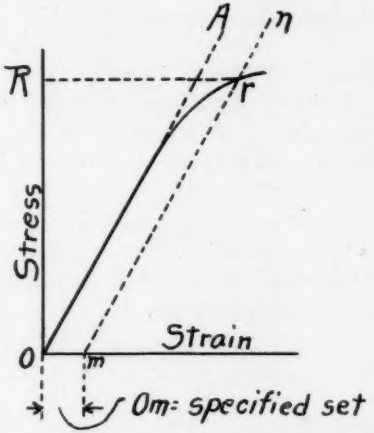


Fig. 7—Determination of "Set" from Stress-Strain Diagram.

iron is the method—"2.—For material whose stress-strain diagram in the region of yield is a smooth curve of gradual curvature." This method is known as the "set" method although what is taken as the set is really only an approximate value of the set. This set method is carried out as follows:

"For nearly all materials, if at any point on the stress-strain diagram such as $r$ in Fig. 7, the load is released the diagram for decreasing load will follow a line, $rm$, approximately parallel to the intial portion, OA, of the diagram for increasing load. Om will then give the approximate value of the permanent set

after the release of the stress OR. The value of this set is given in percentage of original gage length. Thus to determine the yield strength by the "set method," it is necessary to secure data (autographic or numerical) from which a stress-strain diagram may be drawn. Then with the stress-strain diagram (Fig. 7) lay off Om equal to the specified value of the set, and draw mn parallel to OA and thus locate r, the intersection of mn with the stress-strain diagram. Draw Rr parallel to the X axis and then OR gives the value of the yield strength.

In reporting values of yield strength obtained by this method, the specified value of "set" used should be stated in parentheses after the term yield strength. Thus:

Yield strength (set = 0.1 per cent) = 52,000 lb. per sq. in. indicates that a stress of 52,000 lb. per sq. in. the approximate permanent set of the material reached the value of 0.1 per cent of the original gage length."

21. It will be noted that the arbitrary limiting set chosen would vary for different materials and for different services. For the cast irons whose tests are described in this paper the value chosen was 0.1 per cent apparent set.

## DISCUSSION

J. B. KOMMERS,[1] (*Submitted in Written Form*): These results in this paper are interesting from a number of aspects. One thing which impressed me was the quenching and drawing treatment of cast iron *B*., which had its tensile strength increased 59 per cent, and its endurance limit for completely reversed flexure increased 19 per cent. Just as cast iron can now be manufactured to develop a variety of strengths for various purposes, so the heat treatment of cast iron will undoubtedly be used to develop still further possibilities.

The results show that the endurance ratio, that is, the ratio of the endurance limit for completely reversed flexure stresses to the ultimate tensile strength, varied between 0.33 and 0.44, with an average of 0.40 In Table 1 (of this discussion) are listed eight other high strength cast irons with tensile strengths of about 40,000 lb. per sq. in. and higher. The first five results in the table are taken from the 1933 A.S.T.M. report on "Impact Testing of Cast Iron," the tensile results being for a specimen 0.5 in. in diameter. The last three results are taken from the 1928 A.S.T.M. paper by the writer on "The Static and Fatigue Properties of Some Cast Irons," the tensile results being for a specimen 0.33 in. in diameter. It will be noted that the endurance ratio varies between 0.43 and 0.57, the average being 0.48. This higher value may be due to the fact that in these tests special precautions were taken to prevent vibration effects by mounting the fatigue machine on spiral springs.

**Table 1**

ENDURANCE VALUES FOR CAST IRON

| Cast Iron | Ultimate Tensile Strength, lb. per sq. in. | Endurance Limit, lb. per sq. in. | Endurance Ratio |
|---|---|---|---|
| J | 51,440 | 24,000 | 0.47 |
| Q | 40,920 | 19,600 | 0.48 |
| L | 39,200 | 18,200 | 0.46 |
| V | 47,200 | 25,200 | 0.53 |
| Z | 56,700 | 25,000 | 0.44 |
| B | 39,500 | 19,000 | 0.48 |
| H | 51,000 | 22,000 | 0.43 |
| K | 42,500 | 24,100 | 0.57 |

Some of the results in Table 4 of the paper are interesting. The writer does not recall that anyone has previously reported fatigue results for cast iron under torsion. Tests on steel have indicated that in torsion the range of stress is approximately constant whether the stress is completely reversed or whether it varies from zero to a maximum. In Table 4, the values in column 4 must be doubled to get the range of stress. The results then indicate that for cast iron the range of stress is not constant for the same material, being in each case greater for completely reversed stresses.

[1] University of Wisconsin, Madison, Wis.

It is always of interest to see how well experimental results fit various formulas which have been suggested for computing results. In 1922, Moore, Kommers, and Jasper suggested the following formula for calculating the maximum stress for any cycle of stress in fatigue, for steels, when the endurance limit for completely reversed stresses in tension and compression was known:

$$S_{max} = \frac{3\,S_{-1}}{2 - r} \quad \ldots\ldots (1)$$

$S_{max}$ = maximum unit stress in any cycle, lb. per sq. in.

$S_{-1}$ = endurance limit for completely reversed stresses, lb. per sq. in.

$r$ = ratio of minimum to maximum stress for any cycle.

In Table 2 (of this discussion), this formula has been applied to the cast iron results of Table 4 in the paper under discussion. Using the endurance limit for completely reversed stresses from Table 4, the value of $S_{max}$ has been computed from formula (1). This computed value is then compared with the actual value of $S_{max}$ obtained by experiment when the range of stress was from zero to a maximum. It is seen from Table 2 (of this discussion) that in three cases out of five the results check almost exactly, while for the other two results the computed values are too high.

**Table 2**

RESULTS OF CALCULATION OF MAXIMUM FATIGUE STRESS IN CAST IRON

| Cast Iron | $S_{max}$ Computed lb. per sq. in. | $S_{max}$ Experimental lb. per sq. in. |
|---|---|---|
| A | 28,500 | 23,000 |
| B | 31,600 | 32,000 |
| B′ | 37,500 | 38,000 |
| C | 33,000 | 27,000 |
| D | 33,000 | 33,000 |

Another formula for the same purpose, which has been used by Professor Haigh for steels, is the following:

$$a = S_{-1}\left(1 - \frac{S}{u}\right) \quad \ldots\ldots (2)$$

$a$ = alternating unit stress, or semi-range of stress, lb. per sq. in.

$S_{-1}$ = endurance limit for completely reversed stresses, lb. per sq. in.

$S$ = steady stress or mean stress, lb. per sq. in.

$u$ = ultimate tensile strength, lb. per sq. in.

For the case of a stress range varying from zero to a maximum, $S_o$ will be used to designate the maximum stress. For this case, since $2a = S_o$ and $2S = S_o$, formula (2) becomes:

$$S_o = \frac{2\,u\,S_{-1}}{S_{-1} + u} \quad \ldots\ldots (3)$$

In Table 3 (of this discussion), $S_o$ has been computed from formula (3) using $S_{-1}$ and $u$ as determined from experiment. The computed and actual experimental values of $S_o$ are compared in the table. It may be said that in general the computed and experimental values agree fairly well.

**Table 3**

RESULTS OF CALCULATION OF MAXIMUM FATIGUE STRESS IN CAST IRON ACCORDING TO HAIGH FORMULA

| Cast Iron | $S_{-1}$ Experimental lb. per sq. in. | $u$, Experimental lb. per sq. in. | $S_o$ Computed lb. per sq. in. | $S_o$ Experimental lb. per sq. in |
|---|---|---|---|---|
| A | 19,000 | 44,000 | 26,500 | 23,000 |
| B | 21,000 | 48,000 | 29,200 | 32,000 |
| B′ | 25,000 | 76,500 | 37,700 | 38,000 |
| C | 22,000 | 55,000 | 31,400 | 27,000 |
| D | 22,000 | 56,500 | 31,600 | 33,000 |

F. G. TATNALL:[2] A.S.T.M. Standard E8-33 Section 26 describes the "Set Method" for obtaining the yield strength value from a stress-strain diagram. Where the diagram is a smooth curve of gradual curvature in the region of yield, the method describes the drawing of a construction line parallel to the modulus line of the material at a distance to the right equal to the specified value of "set". The intersection of this arbitrary line with the stress-strain curve referred to the "load" co-ordinate represents the value of yield strength.

The stress-strain diagram of most metallic materials exhibits a straight modulus line of sufficient length to permit drawing the above mentioned construction line parallel to it.

In the stress-strain curve of cast iron, there is no straight section of the curve, it begins to bend at zero load. In such a case, there is no straight modulus line to which we can draw the construction line parallel. How, therefore, can we determine the slope of the construction line?

J. J. PICCO: The modulus line to which the line for determining yield strength is drawn parallel was taken as the tangent to the stress-strain diagram at the zero-stress point. This practically coincides with a straight line through the first few (low stress) points of the stress-strain diagram.

CHAIRMAN J. T. MACKENZIE:[2] I personally disagree with the use of the term "yield strength" as applied to cast iron. It might be interesting to determine that property after the material has been stressed, say, five or six times. If you could then get any further set, the result might be of interest, but I do not think that the first loading to one-tenth of one per cent or any other per cent has any significance in cast iron.

H. F. MOORE, (*Author's Closure, Written*): Mr. MacKenzie has expressed doubt as to there being any practical significance to the "yield

[2] Baldwin-Southwark Corp., Philadelphia, Pa.
[3] American Cast Iron Pipe Co., Birmingham, Ala.

strength" as determined by the writers, or as determined by any method similar to the one they used. This question of significance will have to be settled by the producers and consumers of cast iron as they write specifications. The laboratory worker cannot determine the *significance* of any property determined in his laboratory; that is emphatically the job of the user or the producer. Stepping aside for a moment from his position as a laboratory man and remembering his days in the machine shop, the writer of this closure does see some significance in the first appreciable permanent set of the cast iron "ways" of a lathe or a planer. However, the question of whether yield strength of cast iron is of sufficient significance to be considered in specifications is one for foundrymen and users of their products to settle.

Professor Kommers' very interesting interpretation of test results, showing that the Haigh formula for range of stress fits results better than the modified Goodman-Johnson formula proposed by Moore, Kommers and Jasper is noted. He notes the somewhat lower endurance ratios obtained by him on very carefully machined specimens in a rotating-beam machine. The difference in endurance ratio (48 per cent instead of 40 per cent) is quite likely due to the difference in machines used. Mr. Kommers also notes that results of torsion tests for cast iron do not indicate that the range of stress is constant, whether the stress is completely reversed or varies from zero to a maximum. The constancy of range in torsion tests in *steel*, and the variation from constancy for cast iron, is to be explained by the fact that in steel the failures are essentially *shearing* failures, while in cast iron they are *tension* failures.

# Sea-Coal Analysis as Applied to Black Sand

By R. E. Aptekar,* Ypsilanti, Mich.

**Abstract**

*While sea-coal has been used for many years to improve the appearance of castings, its exact function has been made the subject of investigation only recently. Such investigations have been handicapped by the lack of an effective method of analysis for sea-coal in foundry sand heaps. In this paper, the author submits a method of analysis for sea-coal which permits the study of the composition and a quantitative determination of available combustible matter in sands. The author also demonstrates the use of the method in black sand analysis. The method depends on the analysis of each shipment of sea-coal to determine the grain fineness number, total carbon, volatile combustible matter and fixed carbon. Total carbon is found by combustion in a standard combustion train and the fixed carbon by driving off the volatile combustible matter. The difference between those two figures is designated as the volatile carbon. It also was found that the clay content of sands exerts an important influence on the accuracy of the methods involved and allowances for such inaccuracies must be taken care of in the manipulations and calculations. The author also discusses the mechanism of the action of sea-coal and applies his methods of calculation to support his contentions. He gives a constitution diagram which is used to explain the action of the sea-coal in foundry sands. An appendix at the end of the paper explains in detail the methods involved. The methods described are useful in making the full analysis of sands possible, in producing consistent finish on castings and in controlling foundry losses.*

* Foundry Consultant.

Note: This paper was presented at the meeting on Sand Control and Research at the 1934 Convention of A.F.A.

1. It is being increasingly recognized by the progressive foundryman that accurate sand analysis plays an important role in the final quality and appearance of castings. Seacoal or other forms of carbonaceous matter have found a wide application in the foundry, both for improvement of finish and the prevention of mold surface deformation. Control of heap and facing sand hitherto has been limited to testing for permeability and strength.

2. While it long has been recognized that finish is determined largely by grain size and proper proportioning of clay, the exact function of seacoal has only recently been made the subject of extensive investigation.[1] This has been due largely to the fact that no effective method of analysis for seacoal in foundry heaps existed. Neither has it been possible to determine with any degree of accuracy the exact content of clay in heap and facing sands due to the presence of undetermined amounts of seacoal.

3. The present paper submits a method for seacoal analysis which permits a study of the composition, as well as the quantitative determination of the available combustible matter in such sands, and demonstrates its use in black sand analysis.

## METHODS AVAILABLE

4. Much published and unpublished work has been done in this field. Bernardine[2] developed a kerosene flotation method which was modified by Dietert and Wakefield.[3] All subsequent methods have depended on the determination of the carbon content of sand. Dietert and Wakefield[4] used a nitric acid oxidation method which depended on removal of the carbon as carbon dioxide with the reduction of the acid to nitrous oxide.

5. For a number of years the writer used, in the plants of a group of large foundries, a method for determining the total carbon content of black sands by combustion in the standard carbon train. This depended on the predetermined analysis of the original seacoal. Since carbon dioxide contains 27.27 per cent by weight of carbon, the sample weight was made:

$$\frac{0.2727}{\text{Total Carbon Content of Original Seacoal}}$$

[1] Hird, B., "The Action of Coal Dust as a Facing Material," TRANSACTIONS A.F.A., vol. 41, pp. 1-19, 1933.

[2] and [3] Dietert, H. W., and Wakefield Jr., H. W., "Sand Control in the Foundry," TRANSACTIONS A.F.A., vol. 34, pp. 244-268, 1926.

[4] Dietert, H. W., and Wakefield, H. W. Jr., Transactions A.F.A. vol. 35, June 24, 1927.

and direct readings in milligrams of carbon dioxide absorbed were taken as the seacoal content of the sands tested. While this method gave consistent results for control purposes, the error in the method lay in the fact that sands once subjected to casting conditions change in the relative proportions of volatile to fixed carbon contents.

## OUTLINE OF THE METHOD SUBMITTED

6. The method here presented is based on the determination of the total carbon content of the sand and its fixed carbon content, and the calculation therefrom of the available combustible matter and the volatile combustible matter in the sand tested.

7. The total carbon method is essentially that developed in the previously mentioned laboratories and outlined under B-1 in Appendix I.

8. Church and Fulweiler[5] have shown that covering coal tar pitch with ten times its mass of ignited sand increased the accuracy of the volatile combustible matter determinations by reducing entrainment. Weiss[6] showed that this increase in accuracy was due to the buffer action of the large excess of the inert sand present. Since foundry sands normally contain quantities of seacoal under 10 per cent it was thought that some application could be made of those factors in determination of the volatile combustible matter content in black foundry sands. It was found that thorough dispersion of the seacoal in the sand resulted in a radical acceleration in the time required to drive off the volatile combustible matter, and that the seven minutes recommended by the accepted method for coals[7] left the sand almost entirely carbon free.

9. Even with reduced time, all efforts to determine the volatile combustible matter directly were uniformly unsuccessful. While it was possible (cf. Table 2) to obtain with satisfactory accuracy, the volatile combustible matter and the fixed carbon values of a sand (series 1 and 2) free of clay, with proportions of seacoal varying from 1 to 10 per cent; and while it was even possible to obtain these values in a mixture of clay-containing sands and seacoal by determining a blank value for the dehydration of

[5] Church, S. R., and Fulweiler, W. H., "The Test for Volatile Combustible Matter as Applied to Coal-Tar Pitch," PROCEEDINGS, A.S.T.M., vol. 28, part II, pp. 848-854, 1928.

[6] Weiss, J. M., "The Volatile Combustible Matter of Coal-Tar Pitch," PROCEEDINGS A.S.T.M., vol. 32, part II, pp. 676-688, 1932.

[7] A.S.T.M. Specification D22-24.

the clay (series 3 and 4); still these results could not be translated to actual foundry sands because there was no consistency either in the amount of combined water of the sands tested or in the amount of dehydration they had undergone.

10. The fixed carbon determination is therefore a modification of the bureau of standards procedure for the proximate analysis of coal and is carried out as outlined in Appendix I under B-2.

## TESTS TO FIX THE METHOD

11. Table 1 shows the composition of the raw materials used in determining the values shown in Fig. 1. This chart is used to determine time and sample size. From these materials, the four basic mixes of sand shown in Table 2 were made, and these were used subsequently in all the tests.

12. Sand 1 was used to determine the time and sample size. Since it was evident that the standard 1 gram sample treated for 7 minutes, as described by the A.S.T.M. method, produced sand practically free of all carbon, time and sample size were varied. To increase accuracy, it was held desirable to make the sample size as large as possible. Test series 1, Table 3, shows results obtained with the best combination of time, using a 5 gram sample

**Table 1**

COMPOSITION OF RAW MATERIALS

| MATERIAL | TESTS | COARSE OTTAWA | FINE ALBANY |
|---|---|---|---|
| Sands | Screen Analysis | On 20 0.68 | On 70 0.12 |
| | | 30 13.64 | 100 2.32 |
| | | 40 68.90 | 140 26.44 |
| | | 50 14.64 | 200 38.82 |
| | | 70 1.36 | 270 15.08 |
| | | 100 0.12 | Pan 7.98 |
| | A.F.A. Clay | nil | 9.22 |
| | " Fineness | 30.1 | 150.0 |
| | Ignition Loss | nil | 1.31 |
| Seacoal | Fineness | 100 per cent thru 20 | 100 per cent |
| | | 100 per cent on 50 | thru 200 |
| | VCM (Volatile Combustible) | 35.8 | 35.1 |
| | Fixed Carbon | 57.4 | 58.8 |
| | Total " | 72.6 | 74.1 |
| | Volatile Carbon (VC) | 15.2 | 15.3 |
| | $R = \frac{VCM}{VC}$ | 2.36 | 2.29 |

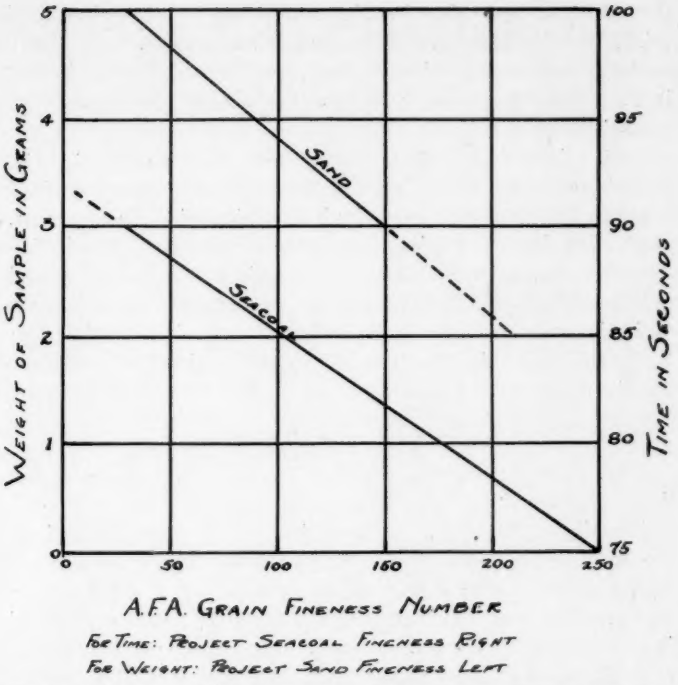


FIG. 1—CHART USED TO DETERMINE SAMPLE SIZE AND COMBUSTION TIME FOR DETERMINATION OF TOTAL CARBON.

**Table 2**

INITIAL SAND COMPOSITIONS USED IN TESTS

| | | | SAND 1 | SAND 2 | SAND 3 | SAND 4 |
|---|---|---|---|---|---|---|
| Mixture | Sand | Type | Coarse Ottawa | Coarse Ottawa | Fine Albany | Fine Albany |
| | | Per cent | 95 | 95 | 95 | 95 |
| | Seacoal | Type | Fine | Coarse | Fine | Coarse |
| | | Per cent | 5 | 5 | 5 | 5 |
| Moisture | | | 1.72 | 1.78 | 5.70 | 4.88 |
| Permeability | | | 331 | 648 | 14.2 | 19.1 |
| Green Compression | | | 1.2 lb. | 0.22 lb. | 4.6 lb. | 4.0 lb. |
| Dry " | | | 5.3 " | 1.0 " | 14.3 " | 12.1 " |

of sand. Test series 3 and 4 show that fine sands retard the rate of volatilization. It also showed that, in a 5 gram sample, not all the water of hydration is driven off from the sand in the time taken to distill the volatile combustible matter. As the clay content in general is higher as the fineness of the sand increases, it was found necessary to reduce the sample size to meet these conditions.

13. The results tabulated in Table 3 are applied in Fig. 1. To determine sample size, project the approximate sand grain fineness upward from the base to its intersection with the upper curve, and follow its intersection left to the graph edge. The indicated readings are in grams of sample required for the fixed carbon determination. Similarly, trace the seacoal grain fineness upward to its intersection with the lower curve and right to the edge of the graph to obtain the time in seconds required to volatilize the volatile combustible matter and the combined water of the sample.

## TESTS APPLIED TO BLACK SANDS

14. The accuracy of the fixed carbon determinations as outlined is determined to a large extent by care and attention to uniformity of practice. It is subject to the same limitations as the accepted method for coals, but to a lesser degree because of the buffer action of the sand. Except for sands of very high clay content (the lower limit of which is about 30 per cent), the time is determined by the seacoal only. In the case of the high clay content sands and especially when very fine seacoal is used, the volatile content of the seacoal evidently is driven off entirely before the clay is dehydrated. The remaining combined water is credited as fixed carbon. As clay contents in heap and facing sands of such high values occur very rarely, and then only with the very finest grained sands for which smaller samples are used, this difficulty does not reduce the usefulness of the method in actual practice.

15. To determine the application of this method to sands in which iron has been cast, sands 1 to 4, Table 3, were used in combinations of various temperatures and sand to iron ratios. Small molds were rammed and poured. In series A through D, Tables 5 and 6, the sand to iron ratios were varied between the limits of 1:125 and 1:2. In series E, C and F, the temperature was varied between 2500 and 2700 degrees Fahr. Total and fixed carbon determinations were made on all these samples as shown in

Tables 5 and 6. Duplicate fixed carbon and total carbon tests also were made on the four original sands for comparison. Results are shown in Table 4.

16. Test series 1 and 2, Table 5, afforded an opportunity for direct determination of the volatile combustible matter content of these samples, for they were clay free. The results show a wide variation in the resultant composition of the seacoal after pouring.

17. Test series 3 and 4, Table 6, shows the volatile carbon values obtained by difference from actual determinations of total carbon and fixed carbon on the sands in these groups. Since it was found impossible to determine the volatile combustible matter directly, it was decided to find the carbon in the volatile combustible matter, designate it as volatile carbon and calculate the

**Table 3**

DATA FOR DETERMINATION OF VOLATILE COMBUSTIBLE MATTER AND FIXED CARBON

| Test No. | Seacoal, Per Cent | Theoretical Analysis | | Actual Analysis | | | Gms. | Time | |
|---|---|---|---|---|---|---|---|---|---|
| | | V.C.M. | F.C. | V.C.M. | F.C. | A.C. | | | |
| 1 | 5 | 1.75 | 2.94 | 1.71 | 2.96 | 4.67 | 5 | 75 | |
| 1 | 5 | " | " | 1.73 | 2.93 | 4.66 | 5 | 75 | |
| 1 | 5 | " | " | 1.70 | 2.92 | 4.62 | 5 | 75 | |
| 1a | 1 | 0.35 | 0.59 | 0.31 | 0.61 | 0.92 | 5 | 75 | |
| 1b | 10 | 3.51 | 5.88 | 3.47 | 5.81 | 9.28 | 5 | 75 | |
| 2 | 5 | 1.79 | 2.87 | 1.73 | 2.93 | 4.66 | 5 | 90 | |
| 2 | 5 | " | " | 1.76 | 2.97 | 4.73 | 5 | 90 | |
| 2 | 5 | " | " | 1.71 | 2.99 | 4.70 | 5 | 90 | |
| 2a | 1 | 0.36 | 0.57 | 0.37 | 0.60 | 0.97 | 5 | 90 | |
| 2b | 10 | 3.58 | 5.74 | 3.42 | 5.86 | 9.28 | 5 | 90 | |
| 3 | 5 | 1.75 | 2.94 | 1.68 | 2.99 | 4.67 | 3 | 75 | Blank |
| 3 | 5 | " | " | 1.72 | 2.94 | 4.66 | 3 | 75 | " |
| 3 | 5 | " | " | 1.76 | 2.89 | 4.65 | 3 | 75 | " |
| 3a | 1 | 0.35 | 0.59 | 0.34 | 0.62 | 0.96 | 3 | 75 | " |
| 3b | 10 | 3.51 | 5.88 | 3.40 | 5.95 | 9.35 | 3 | 75 | " |
| 4 | 5 | 1.79 | 2.87 | 1.74 | 2.93 | 4.67 | 3 | 90 | " |
| 4 | 5 | " | " | 1.77 | 2.87 | 4.64 | 3 | 90 | " |
| 4 | 5 | " | " | 1.73 | 2.86 | 4.59 | 3 | 90 | " |
| 4a | 1 | 0.36 | 0.57 | 0.37 | 0.64 | 1.01 | 3 | 90 | " |
| 4b | 10 | 3.58 | 5.74 | 3.38 | 6.03 | 9.41 | 3 | 90 | " |
| .. | 0 | 0.0 | 0.0 | 1.08 | 0.09 | 1.17 | 3 | 75 | * |
| .. | 0 | 0.0 | 0.0 | 1.15 | 0.04 | 1.19 | 3 | 90 | * |

*Blank on Fine Albany Sand; Blank subtracted from groups 3-4.

volatile combustible matter and total available carbon, which was designated AC. These two series are so calculated.

18. Before developing further the method of calculation, it is well to examine the mechanism of seacoal disintegration as revealed by comparison of the data in these tests.

**Table 4**

DETERMINATION OF UNBURNED SEACOAL IN SAND MIXTURES

| TEST NO. | TESTED VALUES | | DIFFERENCE | R | CALCULATED VALUES | |
|---|---|---|---|---|---|---|
| | T.C. Per cent | F.C. Per cent | V.C. Per cent | | V.C.M. Per cent | A.C. Per cent |
| 1. Theor. | 3.70 | 2.94 | 0.76 | 2.29 | 1.75 | 4.69 |
| Test | 3.72 | 2.93 | 0.79 | " | 1.81 | 4.74 |
| Check | 3.69 | 2.96 | 0.73 | " | 1.67 | 4.66 |
| 2. Theor. | 3.62 | 2.87 | 0.75 | 2.36 | 1.77 | 4.64 |
| Test | 3.66 | 2.90 | 0.76 | " | 1.79 | 4.69 |
| Check | 3.66 | 2.92 | 0.74 | " | 1.75 | 4.67 |
| 3. Theor. | 3.70 | 2.94 | 0.76 | 2.29 | 1.75 | 4.69 |
| Test | 3.68 | 2.99 | 0.70 | " | 1.61 | 4.60 |
| Check | 3.68 | 2.89 | 0.79 | " | 1.81 | 4.70 |
| 4. Theor. | 3.62 | 2.87 | 0.75 | 2.36 | 1.77 | 4.64 |
| Test | 3.67 | 2.93 | 0.74 | " | 1.75 | 4.68 |
| Check | 3.68 | 2.91 | 0.77 | " | 1.82 | 4.73 |

**Table 5**

SEACOAL DESTRUCTION TESTS ON CLAY FREE SANDS

| TEST NO. | POURING TEMPERATURE Deg. Fahr. | Sand : Iron Ratio | TEST RESULTS. | | | | VC | Calculated | |
|---|---|---|---|---|---|---|---|---|---|
| | | | TC Per cent | FC Per cent | VC Per cent | VCM Per cent | TC | R | AC Per cent |
| 1A | 2600 | 1:1.125 | 2.96 | 2.37 | 0.59 | 1.36 | 19.9 | 2.31 | 3.73 |
| 1B | 2600 | 1:1.34 | 2.87 | 2.29 | 0.58 | 1.35 | 20.1 | 2.33 | 3.64 |
| 1E | 2500 | 1:1.50 | 2.91 | 2.29 | 0.62 | 1.46 | 21.3 | 2.35 | 3.75 |
| 1C | 2600 | 1:1.50 | 2.68 | 2.18 | 0.50 | 1.02 | 18.8 | 2.23 | 3.20 |
| 1F | 2700 | 1:1.50 | 2.54 | 2.16 | 0.38 | 0.72 | 15.0 | 2.02 | 2.88 |
| 1D | 2600 | 1:2.0 | 2.47 | 2.04 | 0.43 | 0.93 | 17.4 | 2.16 | 2.97 |
| 2A | 2600 | 1:1.125 | 3.05 | 2.85 | 0.20 | 0.30 | 6.5 | 1.48 | 3.15 |
| 2B | 2600 | 1:1.34 | 3.01 | 2.80 | 0.21 | 0.32 | 7.0 | 1.52 | 3.12 |
| 2E | 2500 | 1:1.50 | 3.22 | 2.80 | 0.42 | 0.79 | 13.0 | 1.89 | 3.59 |
| 2C | 2600 | 1:1.50 | 2.94 | 2.74 | 0.20 | 0.30 | 6.5 | 1.51 | 3.04 |
| 2F | 2700 | 1:1.50 | 2.81 | 2.63 | 0.18 | 0.27 | 6.4 | 1.48 | 2.90 |
| 2D | 2600 | 1:2.0 | 2.84 | 2.67 | 0.17 | 0.25 | 6.0 | 1.46 | 2.92 |

19. It is obvious from comparison of the total carbon tests of series 1 and 3 with series 2 and 4 that under similar conditions of temperature and severity of iron to sand ratio, finer seacoal has the faster rate of breakdown. Greater permeability is seemingly favorable to more rapid disintegration, independent of seacoal fineness. This appears to be the factor having the largest influence. Comparison of any *A* test with the corresponding tests in groups *B, C,* and *D* shows a direct increase in disintegration with increasing severity of use. Similarly, increasing the temperature increases the reduction of total carbon.

20. The most interesting relationship in these tests is shown by the fixed carbon determinations. While, in general, these tests parallel the total carbon determinations in direction of variation, the magnitude of such variations from the original state is remarkably smaller, as is apparent in Fig. 4. This can only be accounted for by the assumption that, on seacoal distillation, a recondensation of the heavy, tarry fractions occurs, increasing the fixed carbon value as the more volatile fractions are driven off entirely or burned.

21. The mechanism of seacoal disintegration by molten metal now becomes clear in its essential details. On introduction of the iron, there is an instantaneous release of large volumes of steam from the moisture in the sand, the evaporation of which absorbs

**Table 6**

SEACOAL DESTRUCTION TESTS—APPLICATION OF GRAPH

| TEST NO. | POURING TEMPERATURE Deg. Fahr. | Sand : Iron Ratio | Test Results TC Per cent | FC Per cent | VC Per cent | VC/TC | Graph R | Calculated VCM Per cent | AC Per cent |
|---|---|---|---|---|---|---|---|---|---|
| 3 A | 2600 | 1:1.125 | 3.49 | 3.02 | 0.47 | 13.5 | 1.89 | 0.89 | 3.91 |
| 3 B | 2600 | 1:1.34 | 3.39 | 2.95 | 0.44 | 13.0 | 1.85 | 0.81 | 3.76 |
| 3 E | 2500 | 1:1.50 | 3.43 | 2.92 | 0.51 | 14.9 | 1.97 | 1.01 | 3.93 |
| 3 C | 2600 | 1:1.50 | 3.31 | 2.83 | 0.48 | 14.5 | 1.95 | 0.94 | 3.77 |
| 3 F | 2700 | 1:1.50 | 3.07 | 2.64 | 0.43 | 14.0 | 1.91 | 0.82 | 3.46 |
| 3 D | 2600 | 1:2.0 | 3.22 | 2.80 | 0.42 | 13.0 | 1.85 | 0.78 | 3.58 |
| 4 A | 2600 | 1:1.125 | 3.56 | 2.97 | 0.59 | 16.5 | 2.07 | 1.19 | 4.16 |
| 4 B | 2600 | 1:1.34 | 3.44 | 2.94 | 0.50 | 14.5 | 1.95 | 0.98 | 3.92 |
| 4 E | 2500 | 1:1.50 | 3.52 | 2.94 | 0.58 | 16.5 | 2.07 | 1.17 | 4.11 |
| 4 C | 2600 | 1:1.50 | 3.38 | 2.90 | 0.48 | 14.2 | 1.92 | 0.92 | 3.82 |
| 4 F | 2700 | 1:1.50 | 3.14 | 2.67 | 0.47 | 15.0 | 1.97 | 0.93 | 3.60 |
| 4 D | 2600 | 1:2.0 | 3.27 | 2.88 | 0.39 | 11.9 | 1.78 | 0.70 | 3.58 |

tremendous quantities of heat from the iron. Obviously, coarse sands requiring less moisture to temper can supply less water and therefore absorb less heat from the iron. As the temperature of the sand mold surface can not rise above the boiling point of water before it is completely dry, it is quite probable that the iron in fine sand molds of low permeability is very much colder before attacking the seacoal than it is in coarse, permeable sands. In addition, lower permeabilities retard the passage of steam through the mold and later the volatile distillate, further increasing the time before the seacoal and clay can be attacked. These two factors account for the fact that seacoal destruction is much less pronounced in fine sands.

### EXPLAINS FORMATION OF MOLD GAS

22. As the temperature of the sand now rises rapidly to above 840 degrees Fahr., the combined water of the clay and seacoal begin to come off as the seacoal becomes pasty or semifluid. Up to this point, there has been no combustion and the entire action has been that of chilling the iron. As the lightest gases of decomposition now appear together with the combined moisture of the clay, the conditions are right for the formation of water gas:

$$HOH + C = CO + H_2$$

This gas ignites explosively at the parting line and mold vents with the appearance of the familiar blue flame of seacoal treated sand molds.

23. Distillation now proceeds rapidly as does also the shrinkage of the clay between the sand grains. The seacoal is now a frothy, swollen mass which flows into the cracks formed in the shrinking bond, as the surface of the mold is deformed by the tendency of the silica grains on the one hand to expand and the clay to shrink. At this stage, the evolution of volatile combustible matter is very rapid. In permeable coarse sands, a large amount of this volatile combustible matter actually is passed through the sand; in the fine sands, the passage is so slow that a very large proportion is recondensed. Only the most volatile fractions are lost. This results in both cases in a decided increase in the fixed carbon value of the sand.

24. As the distillation proceeds to an equilibrium at the surface of the mold, the tarry matter in the cracks of the clay and orifices between the sand grains cokes, exerting a bonding action

which prevents scabs and cuts. As silica grain expansion still continues, the coke shrinks as distillation proceeds—still acting as a binder and to some extent compensating for the silica grain expansion. As most of the heat from the iron has been transferred by radiation and sand is a notoriously poor conductor of heat, the coking action in fine sands does not penetrate very far behind the surface. In coarse sands, the passage of the ignited gases and the presence of relatively much less interfacial resistance to conductivity allows the coking to reach much deeper, especially as the volume of iron is much greater in molds for which coarse sands are used.

25. The calculations in the following paragraph strengthen the belief that most profound changes in the relationship of the volatile combustible portions of the seacoal occur in contact with hot metal. To illustrate, let us examine critically Test 2, Table 4. Its theoretical analysis determined from the original seacoal shows this sample capable of yielding 2.87 per cent fixed carbon and 3.62 per cent total carbon. The difference representing volatile carbon is 0.75 per cent. We note from Table 1 that the value for the ratio

$$\frac{\text{volatile combustible matter}}{\text{volatile carbon}}$$

for the seacoal used in this sample is 2.36. Multiplying,

0.75 (volatile carbon) $\times$ 2.36 (ratio) = 1.77 per cent (volatile combustible matter)

we get the theoretical value. Actual analysis shows values very close to these figures.

## DISINTEGRATION CHANGES VALUES

26. If now we examine similarly in Table 5 the corresponding sample 2-D we find, that after contact with the iron, it contains 2.84 per cent total carbon and 2.67 per cent fixed carbon and, by difference, 0.17 per cent volatile carbon. Calculating similarly, we get:

0.17 (volatile carbon) $\times$ 2.36 (ratio) = 0.40 per cent volatile combustible matter.

Here actual analysis gives a volatile combustible matter value of 0.25 per cent which corresponds to a ratio value of only 1.46. The other tests listed in this table show similar results, all deviating from the ratio value of the original sample of seacoal.

27. Plotting the volatile carbon values against the actual

ratios obtained in these groups, Fig. 2, shows that as the volatile carbon content of the seacoal increases and approaches in the sands the volatile carbon content of the original seacoal, so does the variable ratio value approach the theoretical ratio value. Conversely, Fig. 2 demonstrates that disintegration manifests itself

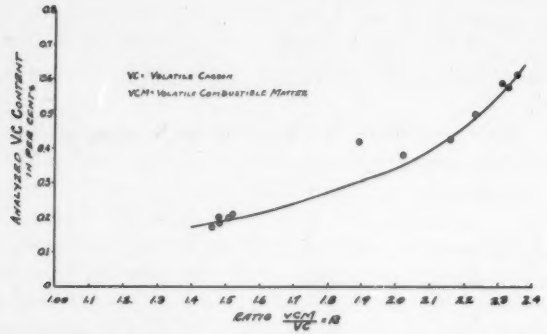


FIG. 2—VOLATILE CARBON VALUES PLOTTED AGAINST THE ACTUAL RATIOS SHOW THAT AS VOLATILE CARBON CONTENT OF THE SEA-COAL INCREASES AND APPROACHES IN SANDS THE VOLATILE CARBON CONTENT OF THE ORIGINAL SEA-COAL, SO DOES THE VARIABLE RATIO APPROACH THE THEORETICAL RATIO.

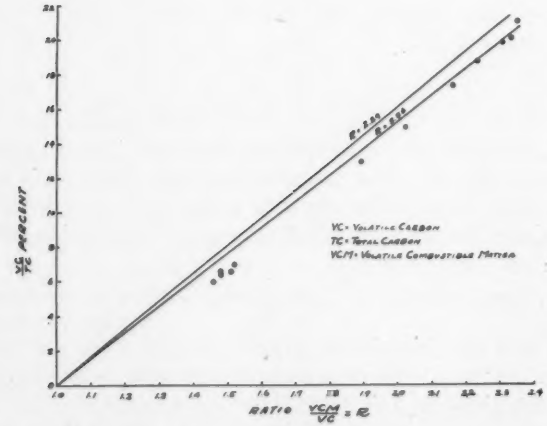


FIG. 3—CHART SHOWING VOLATILE CARBON PLOTTED AGAINST THE RATIO, VOLATILE COMBUSTIBLE MATTER DIVIDED BY VOLATILE CARBON.

not only as reduced volatile carbon values but with proportionally much greater decreases in the ratio value and consequently in the volatile combustible matter content of the used sands.

28. These composite changes may best be expressed graphically by a constitution diagram, Fig. 4, in which the composition of the seacoal is plotted as ordinates against this variable ratio (R) value.

29. In this diagram the left hand extreme shows the composition of an entirely unused seacoal. Its total height AC is the sum of the fixed carbon and the volatile combustible matter with its constituent volatile carbon. The ratio value at this point is the original value of the seacoal. As the coal has not been subjected to heat, the value of the recondensed fixed carbon, shown as a shaded area, is zero.

30. The opposite extreme of this diagram shows the seacoal entirely reduced to coke. No volatile combustible matter is present, and the ratio is 1.00 as the value of both volatile combustible matter and volatile carbon is zero, since total carbon equals fixed carbon and both are lower than the original total carbon. A wide band of recondensed fixed carbon is shown. To the foundryman, this point represents seacoal entirely spent. If coarse seacoal has been used, there are actual coke particles present. Mulling will not show increase in sand strength, at this stage.

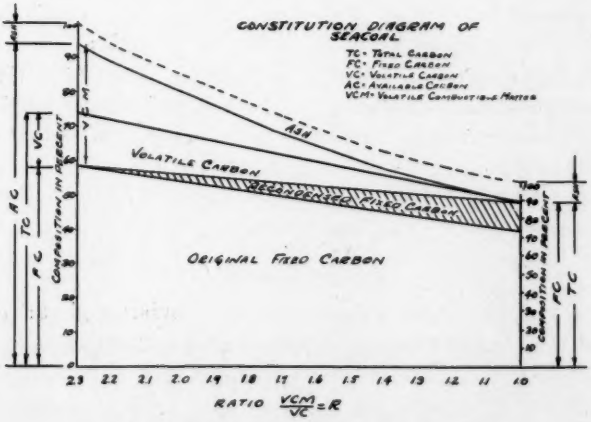


FIG. 4—CONSTITUTION DIAGRAM OF SEA-COAL.

31. All actual seacoal analyses will fall between the two extremes here shown. From the latter extreme, if no addition of seacoal is made only combustion of the coke can take place with increase of ash residue.

32. If now, in our original seacoal analysis, volatile carbon and fixed carbon are expressed as per cents of the total carbon content of the seacoal, we have the means for applying these values to calculation of the volatile combustible matter and available carbon in sands containing clay. We get for the seacoals here used:

| FINE | | COARSE |
|---|---|---|
| 20.9% | Volatile Carbon | 20.9% |
| 79.1 | Fixed Carbon | 79.1 |
| 2.36 | Ratio | 2.29 |

## EXPLAINS CALCULATIONS

33. As in Fig. 2, we now plot this volatile carbon point against the ratio, and draw a straight line connecting the ratio value 1.00 and 0 per cent volatile carbon. This line contains all possible variations of ratio for these seacoals. If on this graph we chart the actual ratio values obtained as tabulated in Table 5, we find that these values fall close to the straight line of Fig. 3. Therefore, we are justified in applying this graph to the calculation of the unknown volatile combustible matter values in groups 3 and 4. In Table 6, the volatile carbon and the fixed carbon values are expressed as per cents of the total carbon, and the ratio values individually found from Fig. 3. Using the formula:

Volatile Combustible Matter = Volatile Carbon × Ratio

the volatile combustible matter values were derived and tabulated. The available carbon is the sum of fixed carbon plus volatile combustible matter.

34. We now rewrite the analysis of sample 2-D as follows:

| | | |
|---|---|---|
| 2.84% | Total Carbon | 100.0% |
| 2.67 | Fixed Carbon | 94.0 |
| 0.17 | Volatile Carbon | 6.0 |

From Fig. 3, we get the ratio R = 1.46. Calculation gives:

0.17 (Volatile Carbon) × 1.46 (Ratio) = 0.25 per cent Volatile Combustible Matter,

and

2.67 (Fixed Carbon) plus 0.25 (Volatile Combustible Matter) = 2.92 Available Combustible Matter.

35. While the derivation of the above formulae may appear somewhat complex, the application to foundry practice is simple and straightforward. Such application divides itself naturally into two general types:

1. Floor foundries having diverse sand conditions and no sand handling equipment.
2. Continuous foundries equipped with central sand conditioning systems.

36. In both cases, it is necessary to know the analysis of the seacoal used. Such analysis must give the volatile carbon in percentages of the total carbon and the ratio value

$$\frac{\text{Volatile Combustible Matter}}{\text{Volatile Carbon.}}$$

From this analysis a curve such as Fig. 3 is plotted.

37. For the rest, it is, in the first case, only necessary to determine fixed carbon and total carbon on the sands to be tested.

$$\frac{\text{Total Carbon} - \text{Fixed Carbon}}{\text{Total Carbon}} = \text{Volatile Carbon}$$

Ratio (R) is then found directly on the graph and volatile combustible matter and available carbon calculated as shown above.

38. In the second case, where sand mixing is uniform and the volume of the sand is such that seacoal disintegration is practically constant, the values R and Volatile Carbon need to be checked only occasionally and combined into a single factor:

Factor = Ratio × Volatile Carbon (per cent of Total Carbon).

Then only total carbon need be determined daily on the sand, and where that value is kept fairly uniform, then:

Total Carbon × Factor = Volatile Combustible Matter
Total Carbon × (100 — Volatile Carbon) = Fixed Carbon; and
Volatile Combustible Matter + Fixed Carbon = Available Combustible Matter.

### APPLICATION TO COMPLETE BLACK SAND ANALYSIS

39. In Table 7 are given three typical actual black sand analyses. In such an analysis, the standard A.F.A. procedure is followed in washing the sand grains free of clay. Part of the seacoal is washed away in the process. When the grains have been dried, the entire sample is transferred without weighing to a flat silica or platinum dish and placed in a muffle furnace to burn free of carbon. The heat is brought up gradually to avoid possibility of splitting the sand grain by expansion strains. When all of the carbonaceous matter has been removed, the carbon free sample is

cooled and weighed; and the grain fineness determined in the usual manner. As there was no clay present, carbonaceous matter represents the only loss on burning.

40. Using Sample C, Table 7, to illustrate, the clay content has been calculated as follows:

| | |
|---|---|
| Clay-free ignited residue | 85.77% |
| Available Combustible Matter | 6.44 |
| Sum | 92.21 |
| A.F.A. Clay substance (Difference) | 7.79% |

**Table 7**

ANALYSES OF THREE TYPICAL BLACK SANDS

| Sand | A* | B** | C*** |
|---|---|---|---|
| **Physical Tests:** | | | |
| Moisture | 5.51 Per Cent | 7.50 Per Cent | 4.83 Per Cent |
| Permeability | 27.0 | 6.9 | 54.0 |
| Green Compression | 7.2 lb. | 11.4 lb. | 6.0 lb. |
| Dry Compression | 42.0 lb. | 82.0 lb. | 74.0 lb. |
| **Chemical Tests:** | | | |
| Clay-free ignited residue | 82.59 Per Cent | 71.51 Per Cent | 85.77 Per Cent |
| Total Carbon | 4.33 Per Cent | 6.26 Per Cent | 5.27 Per Cent |
| Fixed Carbon | 3.55 Per Cent | 5.09 Per Cent | 4.58 Per Cent |
| **Screen Analysis:** | | | |
| On 6 | 0.00 Per Cent | 0.00 Per Cent | 0.00 Per Cent |
| 12 | 0.00 " | tr. " | 0.39 " |
| 20 | 0.78 " | 0.21 " | 0.97 " |
| 30 | 1.18 " | 0.29 " | 2.53 " |
| 40 | 7.45 " | 1.63 " | 14.98 " |
| 50 | 15.69 " | 8.05 " | 29.79 " |
| 70 | 13.32 " | 11.21 " | 21.69 " |
| 100 | 10.78 " | 8.88 " | 9.53 " |
| 140 | 10.98 " | 6.48 " | 2.24 " |
| 200 | 9.61 " | 7.15 " | 1.26 " |
| 270 | 5.79 " | 5.88 " | 0.87 " |
| On Pan | 7.94 " | 21.72 " | 1.56 " |
| Total Grains | 82.59 " | 71.51 " | 85.77 " |
| Available Combustible (by calculation) | 5.22 Per Cent | 8.02 Per Cent | 6.44 Per Cent |
| V.C.M. in seacoal (by calculation) | 1.67 Per Cent | 2.93 Per Cent | 1.86 Per Cent |
| AFA Clay Substance (by difference) | 10.19 Per Cent | 20.47 Per Cent | 7.79 Per Cent |
| AFA Grain Fineness | 100.3 | 152.6 | 52.4 |

*A is a jobbing floor foundry sand, **B is a continuous unit radiator sand, ***C is a sandslinger sand for die-work.

## SUMMARY AND CONCLUSIONS

41. A method has been demonstrated which makes possible a fuller investigation of the functioning and composition of seacoal in foundry black sands. The mechanism of seacoal disintegration has been qualitatively developed, and some of the factors affecting such disintegration have been indicated. Application of this analysis to the full analysis of black sands has been shown.

42. Its usefulness in making such full analyses possible and the value of a study of the seacoal composition and content of sands in producing consistent finish and loss control in the foundry has been demonstrated over a period of years. Its value in application of carbonaceous additions to foundry sands and a better understanding of selection of such addition materials will be demonstrated best by actual foundry experience.

43. The method developed does not give the actual seacoal content, but only the total available combustible matter. The assumption has been made that ash is the equivalent of clay substance. Inasmuch as this ash either adheres to the sand grain by fusion or fluxes with the clay, its quantitative separation is not possible. Whether the ash exerts a bonding action is controversial.

## ACKNOWLEDGMENT

44. Grateful acknowledgment is made to Prof. H. L. Campbell of the University of Michigan Engineering Shops for his aid and encouragement in carrying out this work. Acknowledgment is also due to the F. B. Stevens Co., Detroit, who supplied the many seacoal samples for this and other work on seacoal.

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## APPENDIX I.

### PROCEDURE FOR SEACOAL ANALYSIS

A. Required Preliminary Information:

1. On every shipment of seacoal determine and record for use in future sand analyses:
   a. Grain Fineness Number
   b. Total Carbon
   c. Volatile Combustible Matter
   d. Fixed Carbon

2. From these data express Volatile Carbon as percents of Total carbon, and the ratio as

$$\frac{\text{Volatile Combustible Matter}}{\text{Volatile Carbon}}$$

and plot as shown on Fig. 3.

B. Analytical Procedure:

1. Total Carbon Determination = TC. The apparatus is a standard combustion train in which the oxygen from the tank is led successively through a layer of Ascarite and an overlying layer of anhydrone in a drying tower, and thence into the furnace. From this the gases are passed through a chromic acid-sulphuric acid bulb, according to Lyndell, to remove the sulphur. The $CO_2$ laden air is next passed through a calcium chloride tube filled with Anhydrone and absorbed in an Ascarite filled bulb. The sample used is 0.5 grams for sands containing up to 5 per cent seacoal. The dried sand is covered with alundum in the boat and the boat placed at one end of the hot zone in the furnace to permit maximum travel for the hot gases through the combustion zone. The time for burning is from 15 to 20 minutes.

2. Fixed Carbon Determination = FC. A sample of the dried sand is weighed into a tared platinum or porcelain crucible, which is covered and heated for from 75 to 80 seconds in the full flame of the Meker burner, or preferably in the furnace and crucible described by the A.S.T.M. method.* The exact time is determined from the grain fineness number of the seacoal used; the size of the sample from the approximate grain fineness of the sand being tested (cf. Fig. 1). This crucible is then cooled and reweighed; the loss represents the Volatile Combustible Matter driven off plus the combined water in the clay of the sand. The weighed crucible and its contents are next placed in a muffle furnace or over a burner and all the carbonaceous matter burnt off to constant weight. The loss of weight is recorded as the fixed carbon content of the sample.

* A.S.T.M. spec. D-22-24 (1927 Standards, pp. 535-569.)

C. Calculations:

1. $\frac{\text{Total Carbon} - \text{Fixed Carbon}}{\text{Total Carbon}}$ = Volatile Carbon expressed as per cents of Total Carbon.
2. From Fig. 3, or graph for seacoal used, find Ratio.
3. Volatile Carbon × Ratio = Volatile Combustible Matter in sample.
4. Fixed Carbon + Volatile Combustible Matter = AC, Available combustible matter of sample.

Note: In foundries with continuous systems, the values Volatile Carbon × Ratio can be combined as equal to Factor and calculations from total carbon only made as follows:

1. Total Carbon × Factor = Volatile Combustible Matter.
2. Total Carbon × (100 — Volatile Carbon) = Fixed Carbon.
3. Volatile Combustible Matter + Fixed Carbon = Available Combustible Matter, as above.

## DISCUSSION

BEN HIRD (*Submitted in Written Form*)[1]: Black sand is the base and bulk of molding sand mixtures used in most foundries. Therefore, it is with this type of sand and what happens to it when the mold is being poured, that the value of this paper and future research lies.

Mr. Aptekar's description of the mechanism of sea coal disintegration is very gratifying to me and I am quite in accordance with his conclusions, which only bear out observations formed during my experiments with sea coal.

Referring to paragraph 43, summary conclusions, I do not think the small percentage of ash in a good coal can have any bonding effect worth considering on the sand. The bond obtained from sea coal comes from the liberated tarry matter produced during, and after the filling of the mold.

I have had no opportunity to try out the proposed method of determining the amount of sea coal (or combustible matter) in black sand. However, I am hoping to have an opportunity of doing so in the near future. Its usefulness is without question and it fills a long felt need.

H. W. DIETERT[2]: Would it not be possible to standardize on the size of sample and the time of test, as shown in Fig. 1?

[1] Convener, I.B.F. Technical Committee; Sub-Committee on Sands and Refractories, Upper Cwmbran, Mon., England.

[2] United States Radiator Corp., and H. W. Dietert Co., Detroit.

MR. APTEKAR: I worked quite a long time trying to find a way to standardize on one size sample. I found the rate of distillation in the sample itself was governed very largely by the grain size of both the sea coal and of the sand, and the amount of clay present governed to some extent the length of time that was required, so that both the time and the sample size had to be considered to get consistent results that were quantitative.

MR. DIETERT: Why would it not be possible to use the smaller sample, perhaps the smallest, the one-gram sample, and carry the process a little longer? You are trying to save time by selecting the proper sample, are you not?

MR. APTEKAR: The chief reason was that in a smaller sample on the coarse sand, the time of distillation necessary to obtain our volatile carbon reduced itself to only a very few seconds and the consistency of results became a matter of hair-trigger accuracy in operation, so it became impossible to obtain results that were consistent.

B. C. YEARLEY[3]: It has been my opinion that a buckle was an expansion phenomenon. Perhaps I do not quite understand the author's explanation.

MR. APTEKAR: I pointed out that there is an original contraction and afterwards an expansion of the mold surface. I do not believe that if we had contraction only, buckling would take place, because there would be sufficient strength between the grains of sand at the back of the mold and the face of the mold to resist contraction stresses. The action of partial contraction at the beginning and the expansion afterwards, which is a two-way stress, causes the buckle.

MR. YEARLEY: You infer that there is a difference between the sand adjacent to the casting and the layer immediately back of it—one may be expanding while the other is contracting?

MR. APTEKAR: Yes. Not only that, but even the face of the mold may expand at first and then contract afterwards, which gives an effect like bending a piece of steel back and forth a great many times.

H. B. HANLEY:[4] Which, in the author's opinion, is the more important constituent in the sea coal, the fixed carbon or the combustible matter?

MR. APTEKAR: That depends on your viewpoint. The larger the casting you make, the more important becomes the tarry matter which is the recondensed carbon in the volatile combustible matter. In other words, if we are going to make a large-sized casting, we will take a small amount of sea coal, so that a small amount of gas is generated, and we will take a certain amount of pitch and blend with it, to increase the pitchy matter to bond the grain. The smaller the casting is, the less of tarry matter required.

I find that, generally speaking, the ratio, after use of sea coal on small castings, comes very close to my original 2.3 ratio, while on the large casting we approach very nearly to the ratio of 1.0, where the

[3] National Malleable & Steel Casting Co., Chicago.
[4] American Laundry Machinery Co., Rochester, N. Y.

volatile matter has already been converted to fixed carbon, so we naturally want to supply volatile combustible matter in sufficient quantity to overcome that shrinkage.

MR. HANLEY: In the opinion of the author, could fine ground seacoal be made general in use? During the past ten years there has been a marked tendency to grind seacoal finer, and the use of finer ground coal in the industry has been on the up-grade.

MR. APTEKAR: I cannot give you an absolute answer to that question because the research work that I have done has not covered this field. However, I can say with absolute assurance that there is very little justification in any foundry for the use of a coarse sea coal, because, in the first place, coarse seacoal forms large pockets of gas; in the second place, it forms large chunks of residual coke, which ashes or "rots the heap," as the old foundrymen say.

MR. HANLEY: Will the author tell us more of the bonding strength imparted by seacoal in the conversion cycle of fixed carbon or volatile matter to the tarry residue? This is the first time that I have heard any reference to such bonding strength coming from the tarry material.

MR. APTEKAR: When raw seacoal is mulled cold with sand, there is an increase in green strength, due probably to the large surface tension and area of seacoal particles. When we get beyond that point and heat pitch, which is the material that is left after the first gases are given off, at those temperatures tar is distinctly sticky and the strength, both green and dry, is greatly increased.

This bonding action manifests itself in the sharp increase, particularly, in the dry strength of the sand. Where green tensile strength of the sand is increased, perhaps a matter of 5, 6 or 8 per cent, the increase in dry compression strength, due to the tarry matter, will reach as high as 40 and 45 per cent, in the case of a very fine sea coal, so that the property imparted to sand due to sea coal is not apparent in our first addition of sea coal to the heap at all, but is apparent on the re-use of sea coal.

The point I want to make is that the right amount of sea coal to use is the smallest amount of fresh sea coal that we can and yet keep our amount of pitch the highest amount that is possible to retain in our sand.

The proper way to use sea coal is to add the minimum amount of bonded material that we can possibly use to maintain the minimum strength that we must have in sand. Put in the minimum amount of new sea coal, and, in so doing, actually develop a higher content of available combustible matter and tarry material in well disseminated form.

MR. HANLEY: If you couple with that line of thought a recommendation for the use of finely ground coal in molding sand it would, in my opinion, be a very progressive step in the right direction. We know that a smaller percentage of the finer material will work as well as a larger percentage of the coarser material. This is because the finer particles will go farther in the sand than the coarser particles.

MR. APTEKAR: I agree with your statement that the finer sea coal is easier to disseminate, but I want to go farther than that and say there are fewer harmful effects from the use of fine sea coal than there are

from the use of coarse sea coal, because we can get a more rapid distillation and more rapid dissemination of the tarry matter and more rapid bonding at the initial stage of our casting-cooling operation with the fine, than with the coarse.

MR. DIETERT: We used to use pitch, and we added it with our sea coal as a means of controlling the dry strength of our sand; also it gave us a smaller decrease of the permeability of the sand. We found that both the expansion and the contraction of the sand decreased with the addition of sea coal.

CHAIRMAN W. G. REICHERT[5]: Would the author give us his thoughts on the reaction of sea coal on the surface finish of castings?

MR. APTEKAR: The finish of a casting is proportionately better as we increase the amount of fine pitchy material and reduce the amount of excess gas. Actually, we get a much rougher finish with the use of a lot of new sea coal than we can possibly get with the use of a small amount of new sand and a small amount of sea coal sufficient to give us the replenishment and the maintenance of our sea coal content.

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[5] Singer Mfg. Co., Elizabethport, N. J.

# Selecting Foundry Conveying Equipment

By R. J. Heisserman,* Phildelphia, Pa.

**Abstract**

*To be sure of the soundness of an investment, the opportunity should be investigated so that the investor is not led astray by promises of large immediate returns. The same procedure should be followed when foundry conveying equipment is selected, according to the author. The author outlines the steps leading up to the selection of a continuous molding and pouring system and points out that a thorough survey should be made to determine whether such a system would benefit the prospective purchaser. He also outlines the survey that should be made by the prospective purchaser to assure himself that he is getting the best possible unit for his particular foundry and one that will have both low operating and maintenance costs. He outlines a prospective installation both from the engineer's and the purchaser's standpoint and gives a list of various types of equipment from which to choose. He also shows how the unit should be installed to provide for additions and illustrates such an addition for handling castings.*

1. The dictionary informs us that to invest is "to lay out (money or capital) in the purchase of property for permanent use as opposed to speculation", or "to use money for any purpose from which profit is expected", and that investment is "the act of investing capital productively".

2. Opportunities for investment are many and varied. The layman, with his lack of experience, will be drawn by the "glitter" or promised large, immediate return for an investment. The seasoned investor will first try to determine its soundness as well as to be assured that it will prove reasonably profitable. With this assurance, he is willing to accept a lower rate of return on his money.

* Engineer, Link-Belt Co.

Note: This paper was presented at a session on Materials Handling at the 1934 Convention of A.F.A.

The layman, who falls for the promised high return, unknowingly, is speculating.

3. A like comparison can be made in the selection of foundry conveying equipment. Inexperienced foundrymen frequently are tempted to install low-priced equipment that promises all the returns of the proved, highly-developed system. There have been cases where these speculations, gambles, or experiments have worked after a fashion for a short period. Then the losses from poor castings (due to improper preparation of the sand), high maintenance cost (due to the use of equipment not suitable to the handling of foundry sand, molds or castings), and general disorganization of the entire plant (due to frequent shutdowns for one cause or another) have resulted in complete loss of expected returns.

4. To rebuild such a system to obtain the proper operation, would cost more than the difference in first cost between the good and the poor installation, while if the unit is discarded, the investment is completely lost. Records show that poor equipment has caused complete failures, and it has taken years for the companies that have gone through such an experience to regain their faith in mechanical handling equipment sufficiently to consider another system.

5. To complete the comparison, we have the seasoned investor, who has had previous experience with foundry conveying systems, or who has made a thorough study of those in operation, and as a result, recognizes the fact that proper engineering and quality of product must receive first consideration. He desires a system with low operating and maintenance cost that will meet competitive prices with quality castings for many years after installation. The small extra premium he pays over first cost of the poor investment could be classed as insurance, at a low rate, covering a guarantee of successful operation.

6. As an example of good investment, let us consider the steps leading up to the selection of a continuous molding and pouring unit for a gray iron foundry in which duplicate floor molding is being done with one heat of about 40 tons being poured in an afternoon.

7. Several reasons have caused this foundry to consider mechanical methods; keen competition, the need for increased production without increasing floor space, better working conditions, uniformly improved quality of product, any others that go hand in hand with a systematic, orderly, continuous molding unit.

8. The leading conveyor manufacturers who specialize in foundry equipment are called in for consultation. After a survey to determine whether the volume is sufficient to warrant the installation of continuous molding and pouring equipment, and whether the product is suited to mechanical handling, the prospect should visit various foundries where a similar product is being produced mechanically.

9. Layouts are next submitted. This is a very important step in securing a good investment, as a system not properly balanced in operation, although made up of good individual parts, may cause confusion by overlapping of traffic and thus not gain the desired results. Consideration must be given to the relation of the pouring zone to the cupolas; the molders to the core rooms; and the shakeout to the cleaning room. The number of molders must be balanced with the length of pouring and cooling zones, and if cope and drag molding machines are used, their relation to each other must result in the best operating conditions for molding, setting of cores, closing and placing of complete molds on the conveyor with the least manual effort. Provisions must be made for returning the flasks to the molders and storing them in a convenient location for re-use.

## FORETHOUGHT IS REQUIRED

10. Many other details of operation that go to make up a successful system must be considered, such as the number of molds and amount of sand to be handled per hour. Unless the prospect has had previous experience with mechanical equipment, he is likely to underestimate the possibilities of his molders when aided by suitable conveying equipment, and fail to provide sufficient capacity for the system to obtain the maximum return.

11. Consideration also should be given to the possible addition of other units or the mechanical handling of the castings to the cleaning room at a later date. So that these additions will have all advantages to be gained from the original installation, forethought of future additions in the planning stages may save considerable money, time and shutdowns when additions to the system are installed.

12. The introduction of new sand into the system, and the removing of refuse, including the separation of the magnetic material from the refuse, should be performed at the most convenient location to minimize handling to and from the system. Provision

or means for circulating the sand to and from storage and the preparing and distributing units should be made. This is called a closed circuit system.

13. This type system has advantages, such as taking care of the overflow sand from the distributing conveyors, reworking the sand after the system has been shut down for a length of time, etc. A small continuous amount of prepared sand discharged from the distributing conveyors, mixes with the hot sand in the shakeout conveyors, thus providing a cooling and pre-tempering beneficial to the sand. It also provides seasoning in the storage tank. The surplus sand handled also is an assurance that the molder's sand hoppers always will be full.

### SYSTEM SHOULD BE COORDINATED

14. Conferences between the investor and his staff, with the sales engineers, to insure coordination of actual operating conditions with the requirements of a continuous system, should result in the most satisfactory layout possible for the conditions.

15. A proposal covering all the units that go to make the complete system then can be submitted for consideration from an investment standpoint. Many types of conveying and preparing units are used in foundry systems, each of which, when correctly applied, properly performs the duty expected of it. The list shown in Table 1 gives some idea of the large variety from which to choose.

16. Other types of conveyors are used successfully in foundries for handling such materials as coke, pig iron, scrap, limestone, powdered coal, hot metal, refuse, etc., but, since these are not directly interlocking with the mold, sand and castings handling subject of this paper, no further reference will be made to them.

17. Several propositions are received by our investor, and we shall look over his shoulder as he selects the one that finally is purchased and note the units proposed. Fig. 1 shows a typical installation and the units included are as follows:

1. Mechanical vibrating shakeout screen.
2. Shakeout hopper with feeder.
3. Shakeout reciprocating conveyor.
4. Belt bucket type elevator.
5. Magnetic belt conveyor.
6. Circular storage tank with revolving plate feeder.

**Table 1**

VARIOUS TYPES OF UNITS AVAILABLE FOR CONTINUOUS MOLDING AND POURING SYSTEMS

*Shakeouts:*

Vibrating gratings operated by air vibrators.
Bumping gratings operated by jolt machines.
Bumping gratings operated mechanically.
Vibrating screen operated mechanically or electrically.
Suspended air vibrators over stationary gratings.
Manual or crane shakeout over stationary gratings.

*Shakeout Hoppers:*

Used as storage medium.
Used to collect and direct flow of sand to shakeout conveyor.

*Shakeout Conveyors:*

Belt, apron, reciprocating, drag chain and flight conveyors.
Drag scraper conveyors.
Pivoted bucket conveyors.

*Screens:*

Revolving trunnion or through shaft types, hexagonal or circular.
Breaker trunnion type.
Vibrating, operated mechanically or electrically.

*Magnetic Separators:*

Magnetic pulley at discharge of belt or apron conveyor.
Suspended magnets over conveyor.
Suspended magnetic conveyor over sand conveyor.

*Elevators:*

Belt or chain bucket type.
Inclined apron or belt conveyors.
Pivoted bucket carriers.
Flight conveyors.

*Storage Tanks:*

Circular with revolving plate feeders.
Rectangular with cutting bar, apron or belt feeder.

*Preparing Units:*

Paddle mixer or pug mill.
Muller type mixers.
Aerators.
Reciprocating conveyors.
Air exhaust system.

*Distributing Conveyors:*

Belt, flight or reciprocating conveyors.

*Molding Sand Hoppers:*

Small or medium capacity, with hand operated gate.
Large capacity, with apron or belt feeder.
Large and small capacity hand shovel type.

*Strike-Off Conveyors:*

Belt, reciprocating, drag chain or flight conveyors.

*Castings and Cooling Conveyors:*

Apron conveyors.
Overhead trolley conveyors with baskets or hooks.
Belt conveyors for castings of temperature less than 300 degrees Fahr.

*Core Handling:*

Belt conveyors.
Trolley conveyors with racks.
Tray elevators and conveyors.

*Mold Conveyors:*

Gravity roll.
Gravity roll with power pusher.
Power conveyor sliding type.
Power conveyor, anti-friction roller type.

7. Muller type sand mixer.
8. Inclined tempering belt conveyor.
9. Double paddle mixer.
10. Conditioner or aerator.
11. Cross belt conveyor.
12. Distributing flight conveyor.
13. Molding sand hoppers.
14. Slide type mold conveyor.
15. Strikeoff conveyors.

18. Other propositions offered, based on various layouts or arrangements, will be built of different types or combinations of units than those given, and the investor, in his desire to obtain the equipment best fitted for his purpose, inquires of the sales engineers why they selected the group offered. In other words, the several layouts submitted may all be capable of conveying sand and molds, but when considering the best preparation of the sand and the operating and maintenance cost, the importance of selecting the various units which make up the entire group readily can be realized.

19. Now consider the reasons, item for item, why the foregoing proposition was selected; first by the sales engineer and, second, by the purchaser as a good investment.

20. *Vibrating Shakeout Screen.* This type screen is mechanically operated, with few moving parts, which results in low operat-

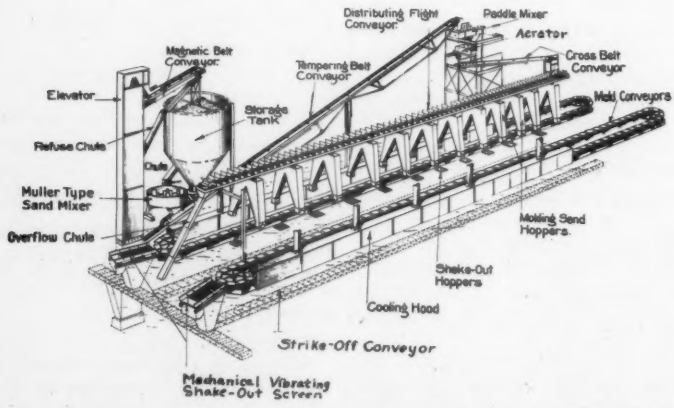


FIG. 1—DIAGRAMMATIC DRAWING OF A CONTINUOUS MOLDING AND POURING UNIT FOR A GRAY IRON FOUNDRY.

ing and maintenance costs. The intensity of vibration is easily adjusted to obtain maximum efficiency and separation of sand and castings is obtained without excessive core sand inclusion. It provides preliminary casting cleaning, screens the sand and removes large refuse metal in addition to its function of removing the casting from the mold. This type of equipment requires minimum space and the screen plate can be changed easily. In addition, the unit is readily enclosed and ventilated.

21. *Reciprocating Type Shakeout Conveyor.* This type conveyor requires a smaller size pit than any other type of shakeout conveyor and there is no pit to clean out as the pit acts as the conveyor trough. This type conveyor cannot be overloaded and provides a uniform feed of sand for the next unit. This feature is accomplished by restricting the opening to the conveyor at the shakeout hoppers. Gates are provided on the shakeout hopper to govern the volume of feed. A preliminary mixing of the sand is provided as it is conveyed and the conveyor action lowers the sand temperature. A minimum number of parts require lubrication. That operation is performed at the floor line.

22. *Belt Bucket Type Vertical Elevator.* A rubber covered belt provides the best medium for carrying buckets which elevate the sand vertically since it withstands abrasion best. A slatted-foot pulley prevents sand building up on the pulley face, thus preventing misalignment of the belt and the open-boot construction makes cleaning and inspection easy. It also prevents clogging. In addition, the ventilated head section relieves sweating and thus reduces the formation of rust inside the elevator casing.

23. *Magnetic Belt Conveyor from Head of Elevator to Storage Tank.* In addition to removing the small iron shot from the sand, the introduction of this unit at this point lowers the head of the elevator considerably and delivers the sand with less force into the storage tank than if it were fed direct from the elevator.

24. *Circular Storave Tank.* The circular type storage tank with revolving disk feeder provides constant, uniform feed from the entire circumference of the tank. Due to the absence of sharp corners and valleys, there is a minimum tendency for the sand to bridge in the tank.

25. *Muller Type Sand Mixer.* Provision is made to feed approximately 25 per cent of the sand required by the system from the tank, through a muller type mixer, where bonding clays are added. This partial mulling of the entire heap maintains the sand

strength which would otherwise be lowered by the constant addition of core sand coming from the castings at the shakeout.

26. *Inclined-Belt Conveyor.* In addition to elevating and conveying material, this conveyor provides a place close to the sand treating man where the tempering operation can be performed. The mulled sand is discharged into a feeder hopper on this conveyor belt. The opening of the hopper is adjustable so that the mulled sand is added uniformly with the sand delivered to the conveyor by the revolving plate feeder at the bottom of the tank.

27. *Paddle Mixer.* A double shaft type paddle mixer mixes the wet and dry sand delivered by the tempering belt. It also thoroughly mixes the mulled with the unmulled sand, resulting in a uniformly tempered and prepared sand. The bottom of the mixer is constructed so that it can be dropped for easy cleaning and the renewable tips of the paddle blades are reversible so that they perform double service.

28. *Aerator.* This machine is located just in front of the point where the sand is fed to the distributing conveyor so that the benefits of aeration and fluffing of the sand are not lost by repeated handling and storing before delivery to the molders. The aerator is of the paddle type with the housing arranged to prevent accumulation of sand on the inside.

29. *Belt Conveyor.* This conveyor, located beneath the conditioner, collects the finally prepared sand and delivers it to the distributing conveyor.

30. *Distributing Conveyor.* The flight type conveyor was chosen as best for this purpose since it provides an automatic feed to the molder's hoppers at all times. Surplus sand is discharged to a chute leading to the shakeout conveyor which returns the sand to the system. The chain and carrying rollers are located at a safe distance from the conveyor flight and trough thereby protecting them from the sand.

31. *Molding Sand Hoppers.* These hoppers are of small capacity as large storage at this point is not necessary with the distributing conveyors continually feeding sand to them. The construction of this hopper is similar to that of a chute with relieving sides and front, which avoids a tendency for the sand to bridge on the sloping side in the back.

32. *Sliding Tray Type Mold Conveyor.* This type conveyor provides smooth operation for handling delicate snap flasks. Its simple rugged construction and small number of moving parts,

insures low maintenance costs. The open-construction, drop-forged steel chain with no rollers is not affected if metal is spilled on it accidentally at the pouring station. This type installation requires minimum space since it is equipped with small (5 ft. diameter) sprockets at the driving and take-up ends and the speed of the conveyor is regulated easily by changing one small sprocket. As the conveyor, including driving machinery, is located above the floor line, no pits are required.

33. *Reciprocating Type Strike-off Conveyor.* The benefits of the reciprocating conveyor also are utilized for this service, namely, shallow pit which requires no cleaning.

34. After the continuous molding and pouring system has been installed and has operated for some time and has proved its efficiency, casting handling equipment may be installed. This equipment, shown in Fig. 2, might consist of a cooling apron conveyor which transfers the castings from the shakeout to the decoring and preliminary cleaning screen; a trunnion type hexagonal screen which discharges the castings to an inclined apron conveyor, which after elevating them, discharges the castings to a picking or sorting belt conveyor beside the cleaning mills. Sprues and scrap metal are discharged to a tub at the end of this conveyor. The refuse sand, which passes through the screen, is dropped to a magnetic belt conveyor which removes all the magnetic material and then delivers the sand to an elevator which, in turn, discharges to a refuse bin.

35. In addition to comparing the merits of various units, the

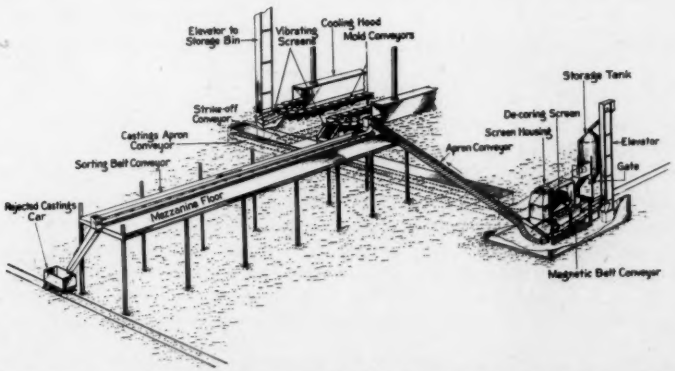


FIG. 2—DIAGRAMMATIC DRAWING SHOWING HOW CASTING HANDLING EQUIPMENT WAS ADDED LATER TO ORIGINAL INSTALLATION SHOWN IN FIG. 1.

foundry engineer will make recommendations as to details of the one selected, such as plain babbitted or anti-friction bearings, open gear drive or enclosed speed-reducer unit running in oil and directly connected to the motor, number of plies and thickness of rubber cover of conveying belt, total horsepower required to operate the system, thickness of steel plates and shapes in hoppers, bins, troughs and structural work, and many other details of equal importance.

36. Unless these details are thoroughly investigated at the time the contract is let, there is the possibility of not discovering their importance until the high maintenance costs call them to attention after the system has been in operation for a comparatively short time.

37. The time required of the purchaser and his organization to make this thorough survey, is a good investment as he will know exactly what he is going to receive for his money and thus eliminate dissatisfaction when the system has been installed. This feature also goes a long way in obtaining coordination of the operations in and surrounding a new conveying system in the shortest possible time.

38. The same care exercised in the selection of the continuous gray iron molding system described, should be used in the selection of systems for foundries pouring malleable iron, steel and nonferrous metals. Each of these foundries has its own problems and, therefore, requires individual study to determine the best layout and selection of units for good investment.

## DISCUSSION

CHAIRMAN E. W. BEACH[1]: I think paragraphs 9 and 11 of Mr. Heisserman's paper should be especially commended to your attention if you are considering mechanical equipment. We learn only from experience and if we take advantage of all of the mistakes that the industry has made, even in some of the later and larger production installations, it will save us a lot of disappointments.

WM. M. BOOTH[2]: In reference to the smaller of the plants that Mr. Heisserman showed in his diagramatic views, in 1925, our company was manufacturing electrical conduit. They were handling some 20 tons of small castings per day. The management considered a mechanized foundry. After due consideration and many reports, such a system was installed, consisting of a 26-mold unit. It has been in operation continuously since that time.

During the depression, the question arose as to whether it should be continued on account of overhead expense. It was continued and it was found that if these castings were made outside it would have cost the company a sum far in excess of our own cost of production. The equipment has been very successful and it has been my charge to see that smooth and machineable castings have been produced. Every part of that plant was put in by Mr. Heisserman as shown in the diagram with great care and attention to detail. I want to speak very highly of it and to say that continuous-pour operation has been of the greatest advantage to our company. In all of the operations, from the cupola to the molding process, the handling of sand, etc., we have met with difficulties such as are to be expected in foundry operations. These difficulties have been fully overcome and were not due to the mechanical equipment. Our daily tonnage was 20 tons, and now it is ten.

CHAIRMAN BEACH: How has the reduction in tonnage affected your costs, according to your experience before the installation of mechanical handling and during this depression when you have had the advantages of mechanical handling?

W. M. BOOTH: Ordinarily, we can produce a casting for one cent per pound cheaper on the system as against the floor. Aside from the overhead, that ratio is maintained in the reduced tonnage, within reason.

JAMES THOMSON[3]: Is it not true that many companies have been fearful of putting in elaborate conveying systems because of the overhead in times such as we are passing through now?

MR. HESSERMAN: That question comes up quite frequently. However, times were good when most of these systems were put in. The companies that put them in, insisted that savings should be sufficient in a year and a half to two years time to wipe off the cost of the system. Theoretically, it will wipe it out that quickly, and in practice, the savings in the majority of cases, was sufficient to clean-up the investment

[1] Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.
[2] Crouse-Hinds Co., Syracuse, New York.
[3] Continental Roll & Steel Foundry Co., East Chicago, Ind.

before the full time production fell off. The overhead at the present time, covering the system, is influenced by the method of bookkeeping used.

It is a fact that you must have, in continuous pouring, sufficient tonnage to keep the system running and to always have hot metal available. You must have enough molds progressing over your molding lines to absorb the rate of melt. This means a balancing of the operations throughout your plant to balance the melt under lower production conditions.

# Notes on Refractories for Electric Furnaces Producing Special Irons

By L. C. Hewitt,* St. Louis, Mo.

**Abstract**

*Certain developments in refractories and their application to the direct and indirect arc furnaces are reviewed. The refractory problem is greater for the indirect arc type and with the possible exception of the direct arc roof different types of refractories are required. The introduction of a comparatively new type of refractory classified as super fire-clay brick has greatly aided in reducing refractory costs for the indirect arc furnaces and should find application as a roof material for the direct. This refractory is noted particularly for its combination of low porosity and high thermal shock resistance together with high refractoriness and volume stability at high temperatures. Careful lining installation with minimum joints, use of proper bonding cement, precautions during preliminary heating, close control over superheating temperatures and the use of some special compounds such as those of barium as a metal cleanser and lining conditioner are among the service factors cited that bear upon the refractory performance.*

1. Recent developments in refractories and their applications have greatly counted toward the increased economical value of the electric furnace for producing gray iron, white iron, "synthetic" gray iron, high test cast iron, high strength cast iron, and alloy iron generally. The advancement has been particularly beneficial to the indirect arc type application in view of the more complex refractory problem involved as compared to the direct arc furnace. Each type of furnace, as an iron producing unit, has its particular application, as is well known to the foundry user. The use is governed by such factors as the continuity of the operation, variability of metal composition from melt to melt,

* Director of Research, Laclede-Christy Clay Products Co.

Note: This paper was presented at a session on Refractories at the 1934 Convention of A.F.A.

use of furnace intermittently as a steel or iron unit, flexibility required as suiting particular circumstances, etc.

2. Due to the fact that the direct arc type furnace necessarily employs a slag coating on the bath, whereas the indirect does not, the refractory service conditions are materially different. The roof lining of the direct arc furnace is the nearest correlation of the lining of the indirect arc type, though in the case of the former the metal is not in direct contact with the refractory as it is in the latter.

3. The refractory cost per ton of metal for the indirect type furnace is, perhaps, roughly about twice that for the direct arc under similar operating conditions. Refractory cost figures for the indirect arc furnace at present seem to range from about $0.50 to $1.50 compared to around $2.50 maximum some years ago. This reduction is due to the intelligent use of better suited refractories. The range in refractory cost is dependent upon such operation factors as temperatures employed, continuity of the production, and type of metal. It is difficult, therefore, to make direct comparison between the efficiency of operation between one unit and another. A figure of $1.25 per ton for refractory cost might be efficient performance in one foundry while the same figure might represent inefficient practice for another. Unless the metal produced in two units is exactly the same, in the same size and type of furnace, and upon the same schedule of production, it is certainly wrong to compare refractory results in terms of melts or tonnage produced.

*Reviews Developments*

4. It is of interest in noting the progress made in refractories and their application to review the situation as it prevailed in 1924. Edwin L. Wilson[1], in treating the subject of electric furnace gray iron, developed the factor that the chief disadvantage of the indirect arc furnace was in the inability of refractories to stand up for a long time at the high temperatures required to make gray iron. He also pointed out that before the rocking was commenced, the part serving as a roof was acted on severely by direct radiation from the arc. It was brought out further that a more refractory lining would solve the main trouble with the indirect arc furnace. Present practice in regard to rocking, is to ro-

[1] Wilson, Edwin L., *"Electric Furnace Gray Iron,"* TRANSACTIONS A.F.A., vol. 32, Part 1, pp. 569-591.

tate the furnace as soon as the charge is made and power applied, which not only speeds up the process but also prevents direct over-heating of the lining due to the direct action of the arc.

5. Bennett and Vogel[2], as recent as 1931, brought out that the phase of refractories presented the greatest opportunity for reduction in the operation expense of the indirect arc furnace. Refractory costs for the particular practice were given at $2.25 per ton of metal which at that time was a considerable development both from the refractory itself and its usage as compared to 1924. Equally important strides have been made in this direction since 1931.

6. Original lining installations consisted of burned refractory shapes. The usage was new and the available product failed by excessive shrinkage and spalling. Some improvement was found by facing the processed refractory with a rammed thin layer of a highly refractory monolithic material. However, close knitting was difficult and early separation occurred. This next advance was the introduction of entire rammed-in linings of what might be termed super-plastics similar to monolithic linings. This construction, while more durable than the previous, required frequent patching due to the tendency for the vitrified inner sections to spall or pull loose from the comparatively unburned outer layer. Moreover, the cost of the special ingredients was necessarily high. Usage then of special refractory brick of similar composition to that of the super-plastics in combination with the latter, further aided in reducing shut downs, though the initial lining cost still remained comparatively high. The most recent accomplishment in refractory efficiency for the indirect arc furnace is the related development and usage of the comparatively low cost super-fire-clay class of brick.

## INDIRECT ARC FURNACE

7. The prevailing tendency in refractories used as linings for indirect arc type furnaces is toward a class of refractories recently developed by refractory producers and for purposes of classification designated as super-fire-clay brick. This new type material combines high refractoriness with constancy of volume at high temperatures, low porosity and exceptional resistance to spalling or thermal shock. Relatively high mullite development is an ac-

[2] Bennett, J. C., and Vogel, J. H., *"Melting of Gray and Malleable Iron in the Indirect Arc Furnace,"* TRANSACTIONS A.F.A., vol. 39, pp. 235-253.

companying property. The economical advantage of such refractories is further enhanced by the fact that their cost is not greatly removed from the first quality fire brick range. As compared to the latter, this new type of refractory possesses in particular the unusual combination of low porosity and non-spalling properties. These factors have been considered to be directly opposed in refractory bodies, that is, to develop one of these qualities was to do so at the expense of the other. Low porosity together with a high fusion or pyrometric cone equivalent (P.C.E.) value counts also in volume stability at high temperatures. The advance has been dependent both upon batch composition and technique in the processing.

*Lining Methods*

8. Installation is usually of standard fire brick shapes for producing a lining thickness of about 9 ins. In one known case at least, the interior lining is 6¾ ins. in thickness made up of arch tile measuring 9 x 6¾ x (2⅜ x 3⅛) ins. in combination with 9 x 6¾ x 2½ in. squares, with that portion of the furnace subject to highest radiation losses being backed up with insulation and the remainder with 2½ ins. of the refractory itself. Definite information on the value of insulation in all instances is lacking. No doubt particular conditions govern the desirability. It is of particular import that the lining be laid with thin joints and with a cement of the so-called super type.

9. Other refractory combinations are the use of two courses of 4½ in. shapes or the same backed up with a brick laid the 2½ in. way on the flat. Replacement is made of the inner circle as needed, usually without disturbing the outer. As the inner 4½ in. lining wears thin, some difficulty is encountered in holding it in place and as a consequence it must be discarded after about 2 to 2½ ins. of wear. In comparison, the 6¾ in. brick withstands some 3 to 3½ ins. of wear before stability is affected and thus renewal is at less frequent periods. Consequent labor saving more than offsets the increased cost of such shapes. The 6¾ in. instead of a 6½ in. arch is used to fit in more readily with the standard square.

10. Respective to tying in the side and end wall brick, two methods seem to be in vogue. In one case, the brick work is interlocking and in the other the construction is separate with an intervening space of an 1 in. or so, which is filled in with a super-

refractory plastic or ramming mixture. The apparent advantage of the latter procedure is that structural repairs can be independently made near the junction of the side and end walls.

*Door Refractories*

11. A matter of rather high upkeep cost has been that of the door opening framework which has consisted of special shape tile. The most serviceable refractory for such design has been a super-refractory tile similar in makeup to the special plastic and cements referred to in this paper as removed from the super-fire-clay brick class dwelt upon. Manufacturing methods to date have not, to the writer's knowledge, made it possible to produce tile of such dimensions from the latter product. It is understood that one or two foundries have effected a considerable economy by working out a means of building the door openings, i. e. lintel, jamb and spout with 9 in. super-fire-clay brick shapes. Information as to the details of the arrangement is not had at this writing.

12. The tile that lines the removable door has been another source of concern due principally to spalling action. Silicon carbide has met that condition but with the disadvantage of high first cost and high thermal conductivity. Special cut super-fire-clay tile are also in this case proving advantageous in at least one case and will probably find further application.

## OUTLINES TREATMENT FOR A NEW LINING

13. A safe practice in breaking in a new lining would be to start off with a coke fire and continue for 6 to 8 hours to red heat. Then bring the furnace under power up to charging temperature of around 2800 degrees Fahr. in 1½ to 2 hours. This schedule may be preceded by an atmospheric drying out or setting period of about 12 hours, but it is questionable if results make it worth while.

*Operating Factors*

14. The superheating temperature and its duration exerts the greatest influence on lining life. As soon as the fusion temperature of the refractory is approached or reached, rapid deterioration proceeds. Metal temperature readings are also lower than that of the wall, hence this should be taken into consideration in determining the superheat limit. An increase of 100, or even 50, degrees as 2900 degrees Fahr. bath temperature is reached,

greatly limits the refractory life. The maintaining of the superheat temperature at the lowest limits required for a particular operation is highly desirable from a refractory cost standpoint. Perhaps in most cases this need not be over 2850 to 2900 degrees Fahr. Close check by means of visual observation of the metal bath, together with optical pyrometer and power input readings, greatly aid in preventing over-heat, even for short periods.

15. Introduction of the charge and closing of the furnace at the end of the day's operation aids in preventing rapid lining cooling and also serves to store considerable heat that otherwise might be lost in the over-night period.

16. A further practice, gaining in favor, is that of the use of conditioners that not only aid in metal cleansing but in servicing the refractory as well. M. A. Baernstein[3], in this connection, relates the introduction of a mixture of barium oxide and barium carbonate into the melt in the ratio of about 1 lb. per ton of metal immediately preceding the superheating temperature. The thin surface glaze, in the apparent form of barium silicate, which is formed on the lining face, stabilizes the silica present and no doubt also aids in reducing metal penetration. The indicated lessening of free silica reduction as effecting silicon pick up thus has an important bearing upon control of metal composition as removed from the beneficial effects to the refractory itself.

*Lining Upkeep*

17. The upkeep of the lining can be accomplished on periodic shut downs by filling in worn sections with either a super type of ramming material or a mixture of such a super type of refractory cement in about the proportion 2/3 to 1/3, depending upon whether it is needed to fill a small hole or apply more or less as a coating or grouting. The matter of skill in the application as developed by practice ties in closely with the resultant success.

## DIRECT ARC FURNACES

18. *Lining Requirements.* This type of furnace operating on the basic or acid process requires that the lining in contact with the metal be strictly basic or acid, i. e. magnesite or silica. The latter usually is employed in the gray iron industry. Frear[4], treats

[3] Paper presented at April, 1934 meeting American Electrochemical Society, Asheville, N. C.

[4] Frear, C. L., *"Gray Iron Production in the Direct Arc Acid Lined Electric Furnace,"* TRANSACTIONS A.F.A., vol. 41, pp. 289-313, 1933.

quite fully the question of the refractories used and methods of installation. From the standpoint of silicon pick-up, it is stated that the bath temperature should not be any higher than need be consistent with the properties required in the finished castings. As in the case of the indirect arc type, this factor of temperature control is highly important since it affects refractory life, particularly the roof.

*Roof Construction*

19. Silica brick or shapes constitute the roof construction. Their advantage lies in the fact that there is no softening tendency until near end point failure. Their disadvantage is high coefficient of expansion requiring careful stay bolt manipulation during heating up and cooling, tendency to spall under fluctuating temperatures and bath contamination with silicon.

20. Super-fire-clay brick, as referred to under indirect arc practices, is finding continued use as a roof lining for electric steel furnaces and it seems safe to predict that its usage will extend to direct arc gray iron furnaces.

*Use of Barium Compounds.*

21. It has been learned lately that 2 per cent of a mixture of barium oxide and barium carbonate, added to the ganister as used for the bottom lining, has worked out advantageously in the instance tried. Sintering is reported to be aided and the tendency toward silicon pickup by the metal reduced. It also is reported that barium compounds, when added to the bath, as in the case of the indirect arc furnace, not only benefit the metal but have a beneficial effect upon the roof as well, due to "dusting" of the roof by the barium as it is introduced into the furnace.

## DISCUSSION

*In the absence of the author this paper was presented by J. A. Kasyer, Laclede-Christy Clay Products Co., St. Louis, Mo.*

G. P. PHILLIPS[1], (*Submitted in Written Form*): Our experience with refractories for the indirect-arc type electric furnace largely confirm the statements made by Mr. Hewitt. When using rammed linings of so-called super-plastics, it was found that considerable trouble was experienced in maintaining the lining and refractories costs were quite high. By changing to the super-fire-clay-brick type of lining, our maintenance troubles were largely eliminated and maintenance, labor costs and refractory costs were reduced approximately 20 per cent.

Since a wide variety of types of irons are produced, some of which are quite hard on furnace linings, the cost of refractories still remains an important item in the cost of producing gray and alloy gray iron castings. It is to be hoped that further improvements will be made in refractory materials available, to the end that refractory costs for the indirect-arc type of furnace may be still further reduced.

H. GAW[2] AND L. L. REINARTZ[3], (*Submitted in Written Form*): The author presents a comprehensive review on some refractories for relatively high temperature services. The paper deals primarily with various applications in the cast iron and cast alloy iron groups, and it is a question whether the data would all hold true at steel melting temperatures. Our discussion must center around the application of refractories in use in direct-arc and induction type furnaces since we do not have any indirect-arc installations. Direct comparisons cannot be made because, as a general rule, the indirect-arc type imposes a more severe requirement on furnace linings than do either of the others.

The various points mentioned relative to refractory life, are quite important, but it seems to us that the problem of quality workmanship in laying the brick or "ramming in" might well be stressed to a greater degree. In the case of brick, the need for uniformily thin joints and evenness of courses is important, while with "ramming" mixtures the consistency of the mix and degree of porosity after ramming are vital factors and to a rather large measure, determine the life of the refractories.

The question of size of brick to be used is probably largely a matter of personal opinion and actual experience. It would seem a small brick would have the following advantages over a larger one; if and when spalling occurred a smaller area would be effected, more joints for expansion and less area within the individual bricks for strains to develop, and a better burnt brick since refractory technique has not entirely solved the problem of uniformily burning large bricks. On the other hand some disadvantage of a small brick are: higher labor in laying the brick since more must be handled and a greater number of joints must be made, and more edges exposed for burning or spalling.

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[1] Metallurgist, Frank Foundries Corp., Moline, Ill.

[2, 3] Metallurgist and Works Manager respectively, American Rolling Mill Co., Middletown, O.

In comparing refractory life, the type of bottom or crucible must be considered. An acid bottom is easier on a roof than a basic bottom because of first, a shorter refining period and secondly, fluorspar is not used. Whenever fluorspar is used on a basic bottom a certain amount of calcium-silicon-fluoride volatilizes and slowly but surely attacks the roof.

It is our opinion that it is a better practice to heat a new lining up with a wood fire and then use coke because coke makes a hot fire and may result in spalling.

Like many other companies, we have done considerable experimental work with various types of brick and "ramming mixtures" and were among the first to use a mullite-brick roof. We have found a sillimanite "rammed" roof to be very satisfactory for a small (1000 lb.) direct arc furnace. The roof has lasted for 450 heats already, and is still in good shape. This has been done on intermittent operations, with an acid bottom, and making a wide variety of plain carbon, low alloy and high alloy steels. It is our understanding that sillimanite breaks down to mullite and silica at around 2830 degrees Fahr. Is it possible, since the roof temperature in steel melting practice will exceed 2830 degrees Fahr., that sillimanite is slowly changing to mullite and excess silica at the inner surface and that in the course of time the entire roof will thus change? We have found that this roof spalls at various intervals in large patches much the same as the author cites. Does this mean that as sillimanite changes to mullite and silica, a plane of weakness is started which ultimately results in a spalling effect?

On a 6-ton direct-arc furnace, a mullite brick roof lasted for 215 heats as compared to about 50 for a high grade silica brick roof. These runs were made with an acid bottom, and were on very intermittent operations and covered a wide range in grades of steel.

JAS. T. MACKENZIE[4]: Mr. Hewitt mentioned the burning in of a rammed lining and the trouble from the contraction of the vitrified interior, pulling away from the unburned exterior. I wonder if anybody ever tried burning in a lining layer by layer, as you do in an arc furnace bottom.

MR. KAYSER: I doubt very much that it would be practical because you would not be able to get any tight connection between the layers; in other words, you have a series of thin layers and the advantage would be doubtful.

MR. MACKENZIE: That method is used with the arc furnace bottom which lasts ten years. Why not with this?

MEMBER: We have never tried building up an entire lining. The furnace we operate is a gas furnace, not an electric furnace, but we did try to build the furnace back to its original size, after it burned out to a certain degree, by re-ramming up to the proper size. We found that we could not get a bond between the old and the new lining.

A. M. ONDREYCO[5]: Would that not be a matter of cost; the cost of installing the segment lining and monolithic lining?

[4] Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.
[5] Westinghouse Air Brake Co., Wilmerding, Pa.

We operate an indirect-arc type furnace, 750-lb. capacity, and we use a segment lining. It costs us approximately $158 to put in a segment lining, including the cost of the lining and removing the old lining. A plant situated not far from us, put in a monolithic lining, tried it on gray iron, and it cost them $600 to install.

MR. MACKENZIE: Did they have the same grade of refractories job?

MR. ONDREYCO: It would not be the same grade. We use a corundite brick segment lining. I think the base was practically the same. I am not so familiar with that. Can you tell us, Mr. Kayser Aren't they both mullite base materials?

MR. KAYSER: The corundum is slightly higher, but they used, no doubt, a superplastic lining which would run very high in cost, but it is doubtful whether the life they would get would offset the cost.

MR. ONDREYCO: They did not get as long life as we did with a segment lining, faced with a sort of monolithic lining, to depth of an inch and a half; this on top of the brick or segment lining.

MR. KAYSER: I think it is definitely true that they are more expensive than segment linings.

MEMBER: We operate 350-lb. electric furnaces for melting brass and have been using the segment lining of the conduit type, and it costs $60. We used a monolithic lining that cost $40 complete. That included the installation, but the corundum lining averaged 1600 heats, and the monolithic has gone 2100 heats and has not worn out.

MR. ONDREYCO: You ram it in from the end. On a bigger furnace you have to build a form inside, and that is where the cost comes in. If you can put your furnace up on end and ram in the refractory, your problem is simplified.

MEMBER: We don't remove the shell from the base. We ram it in from the end.

MR. ONDREYCO: And revolve the furnace as you put it in? The other way is much more difficult. Of course you refer to brass practices and I am talking about iron.

MR. KAYSER: Since the question has come up as to whether it is brass or iron, I should like to emphasize, as Mr. Hewitt pointed out in his paper, the service to which the lining is exposed means a great deal, and you cannot compare a furnace operating on gray iron with one operating on alloy steel, or one operating on brass. It happens occasionally that we are asked to estimate the number of heats that it should be possible to get from a lining. That, of course, depends very much on the service to which the refractory is exposed.

L. C. HEWITT, (*Author's Reply Submitted in Writing*): Mr. Phillips has brought out the desirability of still further improvements in refractories for the indirect-arc type furnace. It can only be hoped that the progress in this direction within the next five years will be as marked as that which has taken place during the past five years. It seems reasonable to expect further increase in refractory efficiency, in view of the fact both the users and producers have greatly advanced their knowledge of requirements and application of lining materials.

Mr. MacKenzie, in bringing to attention the possibility of burning in the rammed lining layer by layer, raises a point that I do not believe has been considered practical up to this time. Mr. Kayser brings out an important factor, *viz.*, that of obtaining continuity from layer to layer. As compared with such practice in electric furnace bottoms, it would seem that the conditions would not be strictly comparable in view of the fact that the bottom is held in place somewhat with the overlying bath of metal. However, Mr. MacKenzie may have brought to attention a possibility that has been overlooked. The chances for adherence between super-imposed layers would be best, no doubt, if the material was applied in the form of sprayed coats rather than being rammed in place, though the maximum thickness that could be applied, at any one time, would probably not be much over ⅛ inch. The draw-back in this sort of application would probably be the necessity for using rather fine grained material to permit of spraying application and thus the lining would be built up from a mixture that would have greater tendency to spall than the coarser rammed-in lining. This would be offset to some extent (just how far one cannot say) by obtaining of a built up lining burned all the way through, as compared to the vitreous inner layer that forms on rammed in linings, with there being a gradation through the lining to practically no vitrification at all. The cost of installing such a unit would, of course, be high.

The difficulty of building-up a lining by means of ramming material, as mentioned, seems to be quite general. The method seems to work out pretty well when filling in holes in the lining that permit of the material to be tied in place, as it were, but fails when attempt is made to build the furnace up to full size in this manner.

The question of monolithic linings versus segment linings, as discussed by Mr. Ondreyco and others further brings out the fact that it is difficult to make comparison between one type of furnace and another. As far as the indirect-arc type furnace is concerned, present experience indicates that the proper type of segment lining is the best practice for gray iron work.

Mr. Gaw and Mr. Reinartz bring out some very pertinent factors relating to steel melting. It is true that the importance of workmanship in lining installations cannot be over-stressed, for no matter how well suited the refractory material might be, it will fail unless properly applied. The question of size of brick to be used is also of importance as Mr. Gaw and Mr. Reinartz bring out. The factor must be decided, no doubt, to fit each individual case. For obvious reasons, it is best, as far as is practical, to use brick which are of standard size.

Respective to the use of wood or coke for heating up a new lining, the advisability would seem to depend upon the type of furnace and refractories used. The practice of using coke, as brought out by the writer, pertains to indirect-arc furnace, laid up with super-fire-clay class of brick.

The notable success that Mr. Gaw and Mr. Reinartz have had with the sillimanite rammed roof for direct-arc furnaces bespeaks excellent workmanship in application, for a rammed construction in a roof is necessarily harder to hold than a side wall or bottom.

The writer agrees with the analysis made that sillimanite in converting to mullite and silica, influences spalling action. There is, of course, a decided heat gradient, between the inner and outer layers of the lining and conversion to mullite and silica takes place in varying degrees throughout the thickness. The silica released, when mullite is formed, will either be in the form of glass or cristobalite, depending upon the subjected temperature. Cristobalite is first formed and then changed to a silica glass at higher temperatures. The silica in the first inch or so of the inner layer of the lining in question would, no doubt, be in the form of a glass, whereas farther back it would be in the form of cristobalite. Cristobalite has a rapid change in thermal expansion from cold up to about 400 degrees Fahr., and thus any rapid temperature changes through that range would cause a strain or plane of weakness at some certain point in the lining, which, according to experience, would seem to be one or two inches from the face. Such a plane will vary with the operating temperatures, thickness of lining and heat gradient.

Since the outer layer, unless the lining is very thin, has not been subjected to sufficiently high temperature to cause mullite conversion, the thermal expansion behavior would be different from that of the intermediate layer. In addition, mechanical strength of the outer layer is relatively low, because it has not been burned-in, so to speak, and thus its ability to withstand the stress is relatively low. The practice of promoting slow temperature change between about 400 degrees Fahr. and room temperature should aid in reducing spalling action of such linings.

# A Contribution to the Study of Fluidity of Cast Iron

**Abstract**

*This report was presented as the Exchange Paper of the Association Technique de Fonderie de Belgique at the Fifth International Foundry Congress. The study was subsidized by the National Belgian Foundation for Scientific Research and was undertaken on behalf of the Association under the scientific direction of Prof. S. Perin and executed by R. Berger, metallurgical engineer, A.I.Lg. The report deals with the influence of carbon, silicon, manganese and phosphorus on the fluidity of cast iron.*

1. Fluidity is defined as, "The tendency for a cast metal to fill a mold completely." From this definition, it is easily seen that fluidity is a complex property and that it is a function of a series of factors, some of which are: (1) Casting temperature of the metal; (2) viscosity of the liquid metal at the temperature passed between the casting temperature and the temperature of complete solidification; (3) heat exchanges between the metal and the mold; and (4) the factors governing solidification of the metal, which play an important role, particularly the interval of solidification and the form of crystalization.

## Factors Governing Freezing

2. Factor (3) introduces a new series of factors, those which govern the freezing of an alloy. Some of these factors are: (a) Those related to the shape of the test piece; (b) those related to the mold and to the contact between the metal and the mold; (c) those depending on pouring; and (d) factors depending on the metal. These four series of variables are those that M. Portevin has grouped under the name of "foundry factors."

3. In a word, fluidity depends both on the metal and on the mold. If a metal is to be specified those factors which are inherent in the mold should be kept constant.

4. The principle of the measurement of fluidity of alloys

Note: This paper was presented at a session on Cast Iron Founding at the Fifth International Foundry Congress and 1934 Annual Convention of the A.F.A. in Philadelphia.

depends on the shape of the test bar to be cast. To determine fluidity, the metal should flow under a constant initial pressure through the length of a specified section. After cooling, the length of the course taken by the metal is measured. To eliminate errors, due to any tilting of the mold, the test casting is shaped like a spiral and cast from the center. This method has the advantage of reducing the size of the mold.

5. Three values must be fixed to define the test piece. These are: (1) The geometrical form of the specimen; (2) the section itself; and (3) the pressure head. For a given metal at a given temperature, test bars will be longer and the test more sensitive as the metal cools more slowly. Therefore, a geometrical form should be adopted of such section that, for a given volume of metal, the minimum surface for contact between the metal and the mold would be presented. For this reason, a circular section is chosen. The cross-sectional area of this section should be as large as possible. In order not to exaggerate the length obtained, a section 8 mm. (0.315 in.) in diameter was adopted. This gives a cross-sectional area of 50 sq. mm. (0.078 sq. in.). The pressure head has been taken as 175 mm. (6.89 in.), the value which, after many tests, seemed to be the most convenient.

6. The following factors influence the nature of the mold:

(1) From the point of view of sensitivity, a mold should have the least possible tendency to chill. Sand molds work perfectly.

(2) The porosity of the sand should be sufficient to assure an easy escape for the gas produced by the contact of the liquid metal with the mold. To make up for a lack of porosity or for differences in porosity of the mold, the end of the spiral is vented to assure the precision of measurements.

(3) The bond strength of the sand should be sufficient to avoid picking up sand, etc., by the liquid metal.

## USE GREEN-SAND MOLDS

7. The molds really should be dry. However, the investigation was carried out in green sand. It actually is much easier to keep the moisture of the sand constant than to have the dryness of the mold the same at all times.

8. These considerations have led to the choosing of the test bar shown in Fig. 1. This test piece has the following properties: A channel of 8 mm. (0.315 in.) diameter circular section, coming

up in a spiral and fed at the center, under a pressure of 175 mm. (6. 89 in.) of metal. The test bar is cast in green sand and a vent is pierced at the end of the spiral.

9. The arrangement of the casting adopted, shown in Fig. 1, is as follows: Two pouring basins, *A* and *C*, situated on either side of the sprue *B*, are joined to it by two runners, *D* and *E*, which are made by hand. The metal is poured from the ladle into *A* and overflows into *B*, under a constant pressure of 150 mm. (5.9 in.) of metal. This avoids the dynamic effect of casting. Pouring is stopped when the metal appears in the basin *C*.

10. In addition, to collect all the first metal and to prevent

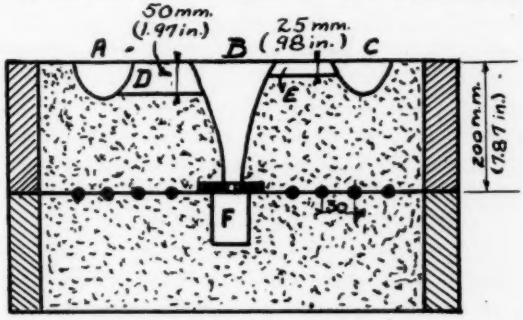


FIG. 1—CROSS-SECTIONAL VIEW OF A FLUIDITY TEST BAR MOLD.

the test bar from filling before the iron rises in *C*, a cup *F* of 230 cu. cm. (14 cu. in.) capacity has been added to this arrangement, below the feeding head.

## DETERMINATION OF PRECISION OF TEST BAR

11. By precision is meant the difference observed between a number of test bars cast under the same conditions of metal and of temperature. "Maximum deviation" means the deviation, expressed in per cent, observed between the length measuring the farthest from the mean, and the mean length; and by "mean deviation," is meant the average of the deviation observed between each test bar and the average length.

12. With a test bar such as has been described, the following results were obtained: Maximum deviation, 4.5 per cent; mean deviation, 2.6 per cent. This precision is not sufficient for our purpose.

13. The length of the test bar depends, among other factors, on the speed of running the metal in the spiral. If this speed varies

between one test and another, the length will vary in the same way, even for the same metal poured under identical conditions.

14. The first cause of the differences observed seemed to be these variations in the speed of starting, variations due to the fact that the metal entered the spiral before it could reach basin *C*. Moreover, experience confirms this hypothesis. If the 230 cu. cm. (14 cu. in.) capacity cup is replaced by a cup of markedly less capacity (100 cu. cm. or 6.1 cu. in.), the mean deviation is noticeably increased. With the 230 cu. cm. (14 cu. in.) cup, the mean deviation was 4 per cent and with the 100 cu. cm. (6.1 cu. in.) cup, it was 9 per cent.

15. To remedy this, two alternatives were available: Either to increase greatly the capacity of the cup, or to diminish the speed of filling up the test piece without changing the speed casting. The first solution seemed certain to lead to the use of a reservoir of much higher capacity, so the second alternative, placing a strainer-core at the base of the feeder-head, as is done with M. Curry's test bar, was adopted.

16. To increase the precision of the test bar without lessening its sensitivity, a diameter for the filter which is greater than that of the spiral should be used. With a strainer core of 10 mm. (.4 in.) diameter, a maximum deviation of 1.4 per cent and a mean deviation of 0.86 per cent was obtained. The optimum time for filling the molds was approximately 4 seconds. For the details of these tests, see *Fonderie Belge*, August, 1932.

## APPLICATION TO THE STUDY OF GRAY CAST IRON

17. Results which have been obtained by the application of this test bar to the study of cast iron now will be discussed First, the laws will be reviewed which Messrs. Portevin and Bastien have shown are established for the behavior of pure metals, binary systems and ternary systems with a relatively low melting point, and which permitted them to work with a cast iron chill mold, thus avoiding the variables inherent in sand molds.

### *Pure Metal**

18. In this very simple case, a mathematical study of the phenomena led Messrs. Portevin and Bastien to establish the following formula:

$$\Lambda = \alpha - \frac{cd(\Theta - F)}{F - \theta} + \beta \frac{Ld}{F - \theta}$$

* Superior numbers refer to the bibliography at the end of the paper.

where $\alpha$ and $\beta$ are the factors depending on the nature of the mold and on the viscosity of the metal; $d$ is the density of the metal; $F$ is the temperature of solidification of the metal; $c$ is the specific heat of the liquid metal; $\Theta$ is the casting temperature and $\theta$ is the temperature of the mold; $L$ is the latent heat of solidification of the metal.

19. This formula shows that: (a), Fluidity varies with the temperature of the mold, following an equilateral hyperbola, and will be indefinite if the temperature of the mold equals the melting point of the metal; and (b), the curves showing fluidity as a function of casting temperature are straight lines, whose angular coefficient depends on the specific heat of the liquid metal. These two laws are verified experimentally, starting with pure metals, zinc, cadmium, and aluminum, which do not oxidize easily.

20. These tests showed that whereas the factor $\beta$ varies slightly between one metal and another and appears therefore independent of the viscosity, the factor $\alpha$ will itself become a function of the viscosity.

*Binary Alloys*[2]

21. In addition to the physical properties of a liquid metal, two factors may influence the running quality of the metal. These two factors are:

(a) The process of solidification (interval of solidification).

(b) Crystallization (crystal form and speed of crystallization).

22. Tests on binary alloys led Messrs. Portevin and Bastein to formulate the two following laws:

1. Fluidity varies inversely as the interval of solidfication. It will be greatest when the melt is homogeneous (as in the case of pure metals, or eutectics), and is least for the saturated solid solutions.

2. Fluidity depends on the crystal form on solidification and is relatively much greater when the liquid forms crystals with convex faces (definite compounds) than when it forms dendrities (solid solutions, bordering on pure metals).

*Ternary Alloys*[3] (*Lead, Tin, and Bismuth*)

23. The previously mentioned authors also state the following with relation to ternary alloys:

(a) Fluidity of a ternary eutectic is an absolute maximum with relation to the fluidities of the eutectics of the binary base systems.

(b) The fluidity of ternary alloys varies inversely as the interval of primary crystallization.

(c) The lines of the binary eutectics are the lines of the crest on the surface representing fluidity of a given alloy. Along these lines fluidity varies inversely as the interval of secondary crystallization.

24. Up to the present time, the Association has made tests covering the following points:

(1) Influence of carbon on the fluidity of iron.

(2) Influence of phosphorus on the fluidity of iron-carbon alloys.

(3) Influence of silicon on the fluidity of iron-carbon alloys.

(4) Influence of manganese on the fluidity of iron-carbon-silicon alloys.

(5) Influence of phosphorus on the fluidity of iron-carbon-silicon alloys.

## INFLUENCE OF CARBON[4]

25. The cast iron studied was an almost pure iron-carbon alloy, containing only 0.10 per cent manganese, 0.20 per cent silicon, and 4.15 per cent carbon. The carbon content was varied by additions of steel, or of finely pulverized anthracite coal. The heats were made in a coke-fired crucible furnace. This method of melting made it possible to get not less than 2.00 per cent carbon, with sufficient superheat.

26. Results have enabled the authors to trace the surface showing relation between fluidity, temperature, and carbon content, shown in Fig. 2. The planes parallel to the plane *X Z* give the variation in fluidity as a function of carbon, for the following temperatures:

| | Deg. Cent. | Deg. Fahr. |
|---|---|---|
| Curve 1 | 1515 | 2759 |
| Curve 2 | 1460 | 2660 |
| Curve 3 | 1395 | 2543 |
| Curve 4 | 1340 | 2444 |

27. The following conclusions can be drawn:

(1) With the casting temperature kept constant, the fluidity increases with the carbon content up to the eutectic concentration (4.3 per cent carbon), then decreases at higher carbon contents.

(2) In the hypo-eutectic region, there is a sudden increase in fluidity around 4.0 per cent carbon.

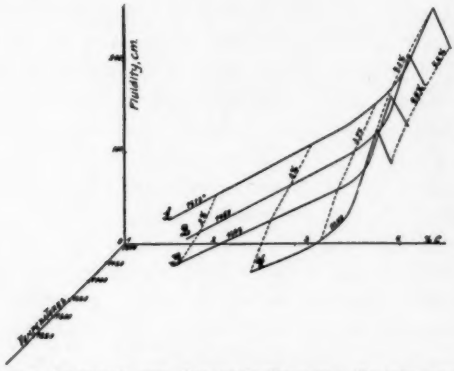


FIG. 2—DIAGRAM SHOWING THE RELATION BETWEEN TEMPERATURE, FLUIDITY AND CARBON CONTENT.

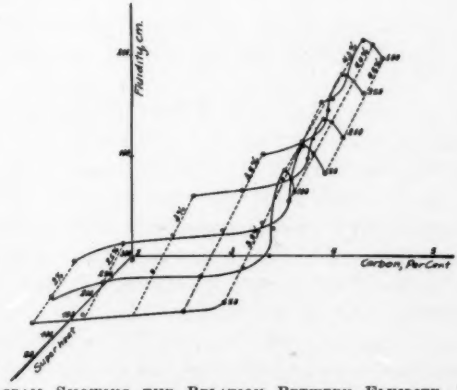


FIG. 3—DIAGRAM SHOWING THE RELATION BETWEEN FLUIDITY, DEGREES OF SUPERHEAT AND CARBON CONTENT.

(3) For decreasing temperatures, the curves have a tendency towards decreased fluidity, although keeping their characteristic shape. The plane sections produced by the planes parallel to $Y$ $Z$ plane give for each carbon content, the variation of fluidity as a function of the temperature.

28. By referring to the iron-carbon diagram, it is possible to get the temperature of the liquidus at all these carbon contents. In Fig. 3, the fluidities, corresponding to temperatures of 50, 100, 200, and 250 degrees Cent. (90, 180, 360 and 450 degrees Fahr.) higher than those of the liquidus, are plotted. The carbon content is plotted along the $X$ axis; the liquid superheat, along the $Y$ axis, and the fluidity, along the $Z$ axis. Thus it is possible to trace in space a diagram showing the variation in fluidity as a function of the carbon content and the superheat of the liquid.

29. The plane sections produced on the surface by the planes parallel to $XZ$, give the variation in fluidity with the carbon content, at the same superheating temperature. These curves approach a maximum at the eutectic concentration. On both sides of that carbon content the fluidity varies inversely as the interval of solidification. In the hypo-eutectic region, a sudden increase in fluidity is observed for a carbon content around 4 per cent, the increase being more marked as the superheat is less important.

## INFLUENCE OF PHOSPHORUS[5]

*Earlier Work:*

30. In a general way, foundrymen accept the fact that phosphorus increases fluidity. The authors have established this fact in some industrial tests. The difficulty of keeping the other elements constant prevented them from exact interpretation of results.

31. It is shown in the work of Saito and Hayashy, and Cary, that phosphorus has a favorable effect on fluidity.[6] Dessent and Kagan also have found a rise in fluidity with increasing phosphorus content.[7] On the other hand, Spencer[8] is of the opinion that if fluidity increases with rising phosphorus (the temperature being constant), it is due only to the lowering of the temperature of the liquidus, and that with a constant superheat, phosphorus would have no influence whatever on fluidity.

32. According to Oberhoffer, phosphorus increases the viscosity of iron-carbon alloys.[6] However, this opinion is nullified by later work of Honda.

*Influence of Phosphorus on the Constitution of Iron-Carbon Alloys*[7]:

33. This equilibrium diagram of the ternary system iron-carbon-phosphorus, shown in Fig. 4, has been studied by numerous workers, including Stead, Wust, Goerens, Dobblestein, Vogel. The liquidus of this diagram is characterized by three curves of the

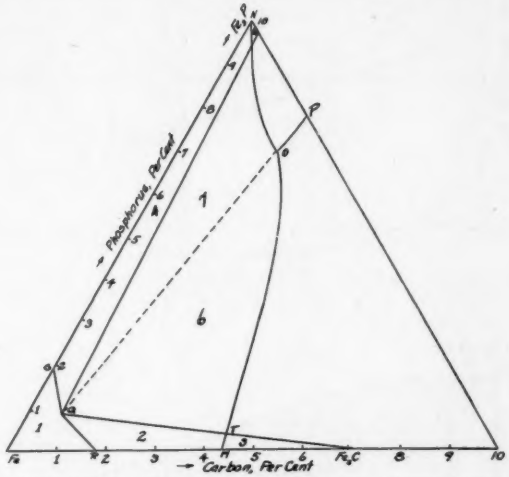


FIG. 4—EQUILIBRIUM DIAGRAM OF THE TERNARY SYSTEM IRON-CARBON-PHOSPHORUS.

binary eutectic *MO*, *PO* and *NO*, converging at the triple eutectic point *O*. The solidus follows the scheme of a triple eutectic $Fe_3C$, *Q*, $Fe_3P$, the two binary surfaces $Fe_3C$, *Q*, *R*, and $Fe_3P$, *Q*, *S*, and the area of complete solubility *Q*, *R*, *S*, *Fe*. For the principal regions of this diagram, solidification can be divided as follows:

(1) Deposition of $\alpha$ or solid solution of $Fe_3C$ and $Fe_3P$ in $\gamma$ iron

(2) $\alpha$ then binary eutectic $\alpha$—$Fe_3C$

(3) $Fe_3C$ then binary eutectic $\alpha$—$Fe_3P$

(4) $\alpha$ then binary eutectic $\alpha$—$Fe_3P$

(5) $Fe_3P$ then binary eutectic $\alpha$—$Fe_3P$

(6) $\alpha$ then binary eutectic $\alpha$—$Fe_3C$, then ternary eutectic $\alpha$ — $Fe_3C$ — $Fe_3P$

(7) $\alpha$ then binary eutectic $\alpha$ — $Fe_3P$, then ternary eutectic $\alpha$—$Fe_3C$—$Fe_3P$

34. An interesting line of the Fe-C-P diagram is the line of deposition of the binary eutectic *MTO* (Fig. 4). Along *MT*, the alloys are made up of the binary eutectic, while *T* and *O* are made up of the binary eutectic and the ternary eutectic. Since increas-

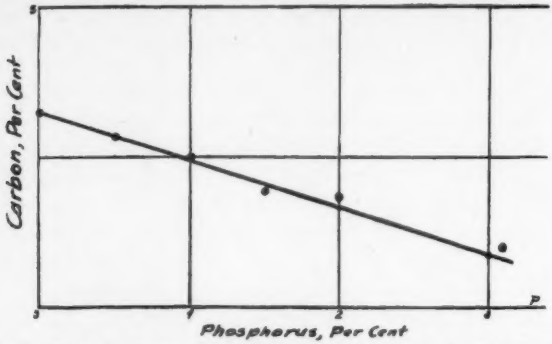


FIG. 5—DIAGRAM SHOWING THE DISPLACEMENT OF THE EUTECTIC CONCENTRATION WITH INCREASING PHOSPHORUS CONTENT. POINTS ON THE DIAGRAM ARE POINTS OF MAXIMUM FLUIDITY.

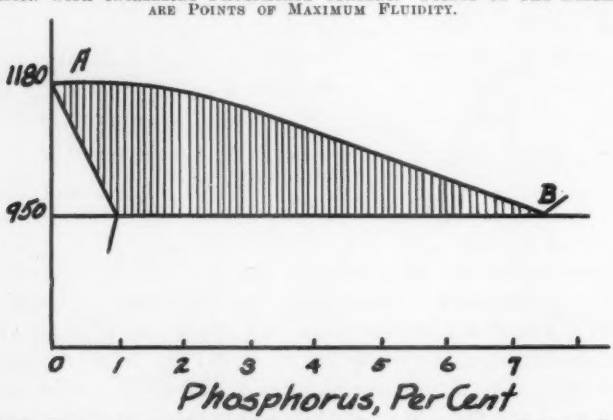


FIG. 6—DEVELOPMENT OF A SECTION MADE BY A CYLINDRICAL SURFACE FOLLOWING *MTO* (FIG. 4).

ing phosphorus lessens the eutectic concentration (see Fig. 5) as well as the eutectic temperature (*AB* in Fig. 6) it is observed that the point *T* (Fig. 4) corresponds to 4.05 per cent carbon and 0.95 per cent phosphorus. The development on this plane, of a section made by a cylindrical surface following *MTO* is represented by Fig. 6.

35. The interval of solidification of the binary eutectic (interval of secondary solidification, the deposition of ternary crystals

being called interval of primary solidification) increases up to 0.95 per cent phosphorus, then diminishes to become zero at the ternary eutectic.

*Results of Research*:

36. (a) *Influence of Phosphorus, with Constant Carbon Content.* Results obtained permit the curves of fluidity as a function

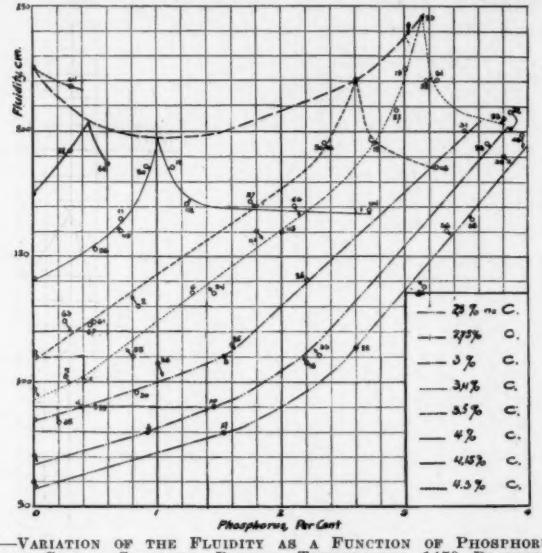


FIG. 7—VARIATION OF THE FLUIDITY AS A FUNCTION OF PHOSPHORUS FOR DIFFERENT CARBON CONTENTS, POURING TEMPERATURE 1450 DEGREES CENT. (2642 DEGREES FAHR.)

of phosphorus, at a temperature of 1450 degrees Cent. (2642 degrees Fahr.) to be traced. These curves are given in Fig. 7. The curves were made on irons having the following carbon contents:

| Curve | Carbon Per Cent | Curve | Carbon Per cent |
|---|---|---|---|
| 1 | 4.15 | 4 | 3.4 |
| 2 | 4.00 | 5 | 3.0 |
| 3 | 3.60 | 6 | 2.75 |
| | | 7 | 2.50 |

37. It will be observed from Fig. 7 that with constant temperature, and constant carbon content, the fluidity increases with the phosphorus concentration, passes through a maximum, and then decreases when the phosphorus becomes higher. This maximum occurs at higher phosphorus percentages, when the carbon is lower. This maximum occurs at higher phosphorus percentages, where the carbon is lower.

38. If, on the curve given by Piwowarsky (Fig. 5) for the variation of the carbon eutectic as a function of phosphorus, the points which correspond to the maximum fluidity are marked, it can be seen that there is good agreement between these points.

39. From these curves, it is possible to draw the following conclusions: "At constant temperature and for the same carbon content, fluidity increases with increasing phosphorus up to the

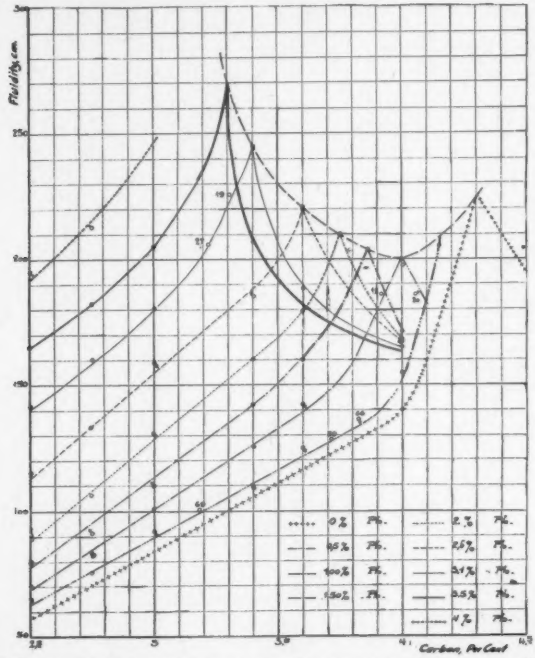


FIG. 8—VARIATION OF THE FLUIDITY AS A FUNCTION OF CARBON FOR DIFFERENT PHOSPHORUS CONTENTS. POURING TEMPERATURE 1450 DEGREES CENT. (2642 DEGREES FAHR.)

concentration corresponding to the eutectic for that particular carbon. For higher percentages, fluidity decreases sharply, then stays fairly constant. In the hypo-eutectic region, the increase in fluidity is more marked as the eutectic is approached."

40. (b) *Influence of Carbon, the Phosphorus being Constant*: It has been shown previously that in the case of iron-carbon alloys, fluidity increases with carbon content, slightly at first, then with a sudden jump at approximately 4.0 per cent carbon. This increase continues up to the eutectic concentration; at higher carbon contents, fluidity decreases.

41. If with the aid of the curves of Fig. 7, the variations of fluidity as a function of carbon, both the phosphorus and the temperature remaining constant, are traced, curves (Fig. 8) are produced which make possible the following conclusions:

(1) In the hypo-eutectic region, fluidity increases with the carbon content. The general shape of these curves remains practically the same as in the case of the iron-carbon alloys. The maximum always occurs with lower carbon when the phosphorus is increased; on the other hand, the angular coefficient of the rectilinear part of the curve is higher as the phosphorus is greater. From this, it is evident that phosphorus lessens the interval of primary crystallization and it does so more rapidly as the eutectic is approached.

2. In the hyper-eutectic region, fluidity decreases with phosphorus content. It will be noticed that for carbon concentrations over 4.0 per cent, the variation is less appreciable.

(3) Fluidity along the line of deposition of the binary eutectic (reproduced as the dotted line on Figs. 7 and 8) decreases with increased phosphorus, then increases with still higher phosphorus.

(4) If the shape of this curve is compared with the variations in the interval of secondary crystallization (Fig. 6), it will be observed that the minimum fluidity (4 per cent carbon—1 per cent phosphorus) practically corresponds to the maximum of the interval of solidification (4.05 per cent carbon—0.95 per cent phosphorus), and that along the eutectic line, fluidity is inversely proportional to that interval of solidification. This confirms the results of Messrs. Portevin and Bastien on the alloy lead-tin-bismuth.

## STUDY OF THE FLUIDITY OF THE TERNARY SYSTEM IRON-CARBON-SILICON

42. Silicon is one of the most important constituent elements in cast iron. It exists in greater or less quantity in all industrial irons, whether cast or wrought. It is incorporated in the metal in the blast furnace at very high temperatures (about 1800 degrees Cent. or 3272 degrees Fahr.) by the reduction of silica by carbon.

*Study of the Iron-Carbon-Silicon System*[9]:

43. Silicon decreases both the limit of saturation of cementite in austenite and the eutectic concentration (Fig. 10). The iron-

carbon-silicon equilibrium diagram (Fig. 9) shows this. In Fig. 9, three different regions are noted:

(a) *I*—Where the alloy is formed immediately after the solidification of the ternary crystals iron-FeSi-FeC. This is the region of steel.

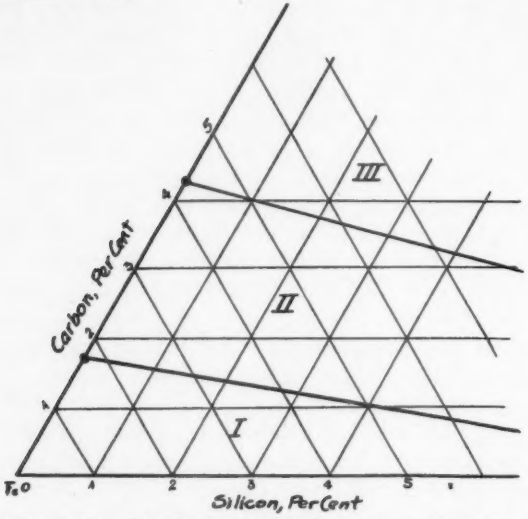


FIG. 9—THE IRON-CARBON-SILICON EQUILIBRIUM DIAGRAM.

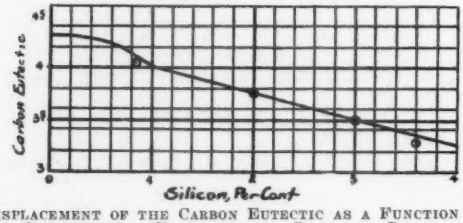


FIG. 10—DISPLACEMENT OF THE CARBON EUTECTIC AS A FUNCTION OF SILICON ACCORDING TO PIWOWARSKY. POINTS ON THE CURVE ARE POINTS OF MAXIMUM FLUIDITY.

(b) *II*—Where the alloys are formed after solidification of mixed ternary crystals, embedded in a binary eutectic (solid solution-$Fe_3C$) which occurs at different temperatures. This is the zone of hypo-eutectic iron.

(c) *III*—Where the alloys are made at the end of the solidification of free cementite (or graphite, after a certain silicon content is reached) in a binary eutectic (Sol-Sol-$Fe_3C$). This is the zone of the hyper-eutectic irons.

44. The binary eutectic is formed at different temperatures. The interval of solidification increases with the silicon content. The temperature of beginning solidifications, which is 1150 degrees Cent. (2102 degrees Fahr.) for pure iron-carbon alloys, is raised by increased silicon.

*Influence of Silicon on Fluidity:*

45. Before this work, very few results giving the influence of silicon to this specific property of cast iron were to be found in the literature. Practical men of the Thomas steel works usually consider silicon to have a thickening effect on iron, an opinion restated by Oberhoffer in his paper in 1924 on the viscosity of cast iron, although the foundryman attributes a favorable effect on fluidity to silicon.

46. (a) *Execution of Tests:* As before, the heats were made in a crucible furnace, heated with coke, using a natural draft. The base iron varied in the course of the tests. The first three series of irons contained 0.20, 1.0 and 1.5 per cent silicon respectively. Series 4 contained between 0.43 and 0.72 per cent silicon while series 5 was a group of synthetic irons. The percentages of carbon and silicon desired were obtained by additions of steel or ferrosilicon, using either 45 or 90 per cent ferrosilicon. To assure perfect homogeneity of all the iron, and to reduce to a minimum the losses from oxidation, the ferro-alloy additions were not made until after the metal was melted, just before superheating.

47. (b) *Results Obtained:* (1) *Base Iron with 0.2 Per Cent Silicon.* The shape of the curves in Fig. 11 gives the variations of fluidity as a function of silicon for constant carbon content for each curve at a temperature of 1450 degrees Cent. (2642 degrees Fahr.). The different curves have the following carbon contents:

| Curve | Carbon Per Cent | Curve | Carbon Per Cent |
|---|---|---|---|
| 1 | 2.50 | 4 | 3.25 |
| 2 | 2.75 | 5 | 3.50 |
| 3 | 3.00 | 6 | 3.75 |
| | | 7 | 4.00 |

48. It will be seen from these curves that fluidity, after having been increased at 0.3 per cent silicon, decreases to pass through a minimum corresponding to 0.50 per cent silicon. After this minimum, fluidity increases up to 0.75 per cent silicon, then again sinks to a minimum at 0.95 per cent silicon. In the rest of this work, the minimum which occurs at 0.50 per cent will be called the first anom-

aly of silicon; the minimum at 0.95 per cent silicon, the second anomaly of silicon.

49. For silicon contents over 0.95 per cent, fluidity increases rapidly, even more rapidly as the carbon content is higher, then slowly up to a new maximum which displaces the preceding ones for that carbon content. These last maxima show, as in Fig. 9, the

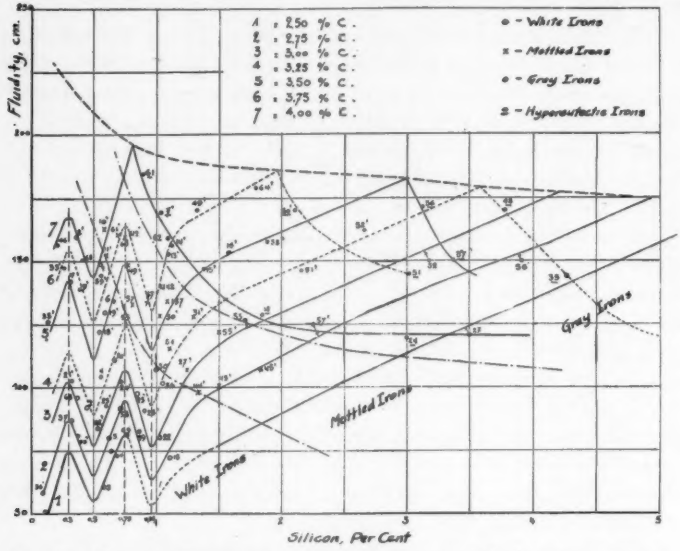


FIG. 11—FLUIDITY CURVES OF AN IRON CONTAINING 0.20 PER CENT SILICON POURING TEMPERATURE 1450 DEGREES CENT. (2642 DEGREES FAHR.)

eutectic concentration with the silicon content considered for that particular carbon content.

50. Curve 7 (4 per cent carbon) shows no second anomaly. This phenomena, which falls in the hypo-eutectic zone, seems to disappear into the eutectic.

51. To discover the cause of these two anomalies (which occur at different carbon contents, but always at the same silicon concentration) a series of test bars 20 mm. in diameter has been examined metallographically to see if there was not some correlation with the phenomenon of graphitization. These examinations permit us to define on the graphs, shown in Fig. 11, the zones corresponding respectively to white irons, mottled irons, and gray irons.

52. From the graphs, it will be noticed that the first anomaly

is entirely in the region of white irons and that the second anomaly falls in the region of the mottled irons (for carbon contents over 3.50 per cent) and in the region of white irons for carbon contents under 3.50 per cent. From this, the conclusion is drawn that there is no relation between graphitization and the anomalies of fluidity due to silicon.

53. If it had been possible to examine the test bars having the same diameter as those of the fluidity tests (8 mm. or 0.315 in.),

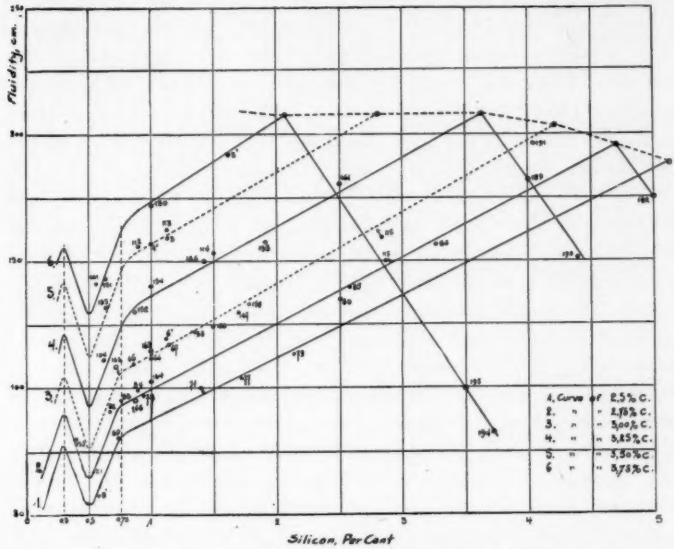


FIG. 12—FLUIDITY CURVES OF AN IRON WHOSE INITIAL SILICON CONTENT IS GREATER THAN 1 PER CENT. POURING TEMPERATURE 1450 DEGREES CENT. (2642 DEGREES FAHR.)

the lines of demarcation of the zones of crystallization would be displaced to the right. This would only confirm the conclusion already reached.

54. It does not seem that these maxima can be explained by the presence of definite compounds, since the equilibrium diagram for iron-carbon-silicon does not show the presence of such compounds in this region.

55. (*2*) *Base Iron with Silicon Between 1 and 1.5 Per Cent:* The curves obtained for this base iron have a different shape from those observed in the other cases and are shown in Fig. 12. Up to 0.75 per cent silicon, these curves are similar to those previously obtained, but for higher contents of silicon, fluidity increases progres-

sively to a maximum corresponding to the eutectic. These maxima of fluidity are present at silicon contents practically identical with those in the first case (Fig. 11). If the iron studied has a silicon content of over 1 per cent, the second anomaly completely disappears, but the first always remains.

56. An important observation in connection with the study of the influence of phosphorus on fluidity was that fluidity increases much more rapidly as the eutectic is approached. In the case of silicon, the reverse is true. It is a new confirmation of the law of Portevin, namely: Fluidity depends equally on the variations of the interval of secondary solidification. In the case of phosphorus, more than 1 per cent phosphorus causes the interval of solidification of the binary eutectic to decrease with the phosphorus content, but in the case of silicon, it increases with the silicon. For this same reason, fluidity decreases along the eutectic line.

57. (*3*) *Base Iron with Silicon Content Varying Between 0.40 and 0.70 Per Cent:* At this point the following problem presents itself: if an iron taken from the furnace with 0.2 per cent silicon is studied, a minimum of fluidity is observed at 0.95 per cent silicon. If, on the contrary, one base iron has a silicon content higher than 1 per cent, this minimum of fluidity is not present. There then should be some critical percentage between 0.2 and 1.0 per cent silicon, at which the second anomaly of silicon disappears. To determine this percentage is the aim of these tests.

58. To do this, experimental irons were made with silicon contents increasing from 0.43 to 0.70 per cent silicon. As has been stated, when the iron studied had a silicon content under 0.48 per cent, the values of fluidity correspond to those given by the curves obtained from the iron studied with 0.2 per cent silicon (Fig. 11). On the other hand, if the base iron has a silicon content over 0.53 per cent, the fluidity values correspond to those given by the curves obtained with an iron whose initial content was above 1.0 per cent (Fig. 12).

59. The critical percentage was found to be between 0.48 and 0.53 per cent silicon. It is probable that this critical content is 0.50 per cent, the minimum point of the first anomaly. From this, it is possible to draw the conclusion: Depending on whether the iron in question had a silicon content lower or higher than 0.50 per cent, the additions of ferro-silicon (or steel) produced or did not produce a sudden fall in fluidity between 0.75 and 0.95 per cent silicon.

60. (*4*) To clarify this phenomenon and determine whether

or not heredity was the cause, the silicon content of a cast iron whose initial content was 1.00 per cent was diminished by the addition of steel in such a way as to place the new irons just one side or the other of 0.50 per cent silicon. These irons were made in a rotary furnace, cast in pigs, then reweighed in the third melt in one crucible. If this phenomenon is a matter of heredity, the anomaly will not be manifested in any instance.

61. The results obtained are as follows:

(*1*) *Iron having a silicon content of 0.55 per cent:* All the results obtained supplied points which fell on the curves corresponding to the tests for fluidity made on pig-iron whose silicon content is over 0.50 per cent.

(*2*) *Iron having an average content of 0.40 per cent:* The points obtained fell on curves obtained using irons of the first melt whose silicon content was less than 0.50 per cent.

62. These facts weaken the hypothesis previously advanced, namely, that it is a question of heredity. *Accordingly, it is possible to conclude this series of tests on the influence of silicon in the following way:*

(a) In an iron whose silicon content is less than 0.50 per cent, whether it is an iron of first or second melt, if the carbon is kept constant, a sudden fall in fluidity takes place between 0.75 and 0.95 per cent silicon. Beyond that percentage, fluidity increases progressively until the content of silicon reaches the eutectic concentration, considering the carbon present. For higher silicon, fluidity decreases, 0.50 per cent silicon constituting the first minimum; if the silicon is lowered still more by steel additions, fluidity increases to 0.30 per cent silicon which constitutes the first maximum.

(b) If, to an iron whose initial silicon is more than 0.50 per cent, increased quantities of ferro-silicon are added, always keeping the carbon constant, fluidity increases very rapidly up to 0.75 per cent, then more slowly to the eutectic concentration for the carbon considered. On this side of 0.50 per cent, a variation analogous to that shown in (1) is noted.

63. These results bring together the opinions of foundrymen and steel men. Since the latter are working usually between 0.3 and 0.5 per cent silicon (Thomas process), it is natural that they would find an increase in viscosity when silicon increases. Foundrymen, on the other hand, keep in the neighborhood of 1 per cent silicon, except for some special jobs, and the results given show

that the fluidity of their metal should vary proportionally with the silicon content.

64. (5) *The objection can be raised that the conclusions, and especially drawing the curves between 0 and 1.0 per cent silicon, are supported by a very small number of results.* This observation would be pertinent if each curve was considered separately; but it must not be forgotten:

(a) That, if what has been called first and second anomaly were due only to the errors of observation, the conclusion would be reached that the precision of the test bar was,

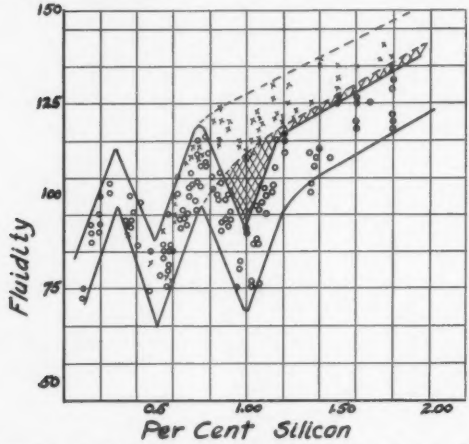


FIG. 13—RESULTS OF FLUIDITY TEST CALCULATED TO 3.0 PER CENT CARBON CONTENT. POURING TEMPERATURE 1450 DEGREES CENT. (2642 DEGREES FAHR.)

under 1 per cent silicon, markedly inferior to that in the other cases, which is not admissible.

(b) That a number of curves have been determined, which confirm each other because they are parallel.

(c) Assuming that the second anomaly disappears or appears according to the base iron used (and that may be true), still these maximum eutectics are present at the same silicon contents for a given carbon. The presence of the second anomaly seems hardly to be denied.

65. Attempting to throw more light on the existence of these two anomalies, (basing the work for this on the parallelism of the curves) the mean coefficient of deviation of fluidity due to carbon between 3.75 and 2.5 per cent has been determined and is 7 cm.

(0.276 in.) for 0.1 per cent carbon. With this value, all results were calculated to the average content of 3 per cent carbon and are reported on the diagram shown in Fig. 13.

66. Two series of curves have been obtained; one containing the results obtained with an iron containing less than 0.5 per cent silicon, the other obtained when the base iron had more than 0.5 per cent silicon[10].

67. An examination of these curves shows:

(1) The respective curves keep the general shape of the group of curves.

(2) The dispersion due to experimental errors is markedly less than the amplitude of the anomalies.

(3) The absence of results in the shaded region separating the lots of curves justifies more than ever the fact that the second anomaly exists.

## INFLUENCE OF MANGANESE

68. At the request of certain steelworkers, the determination of the shifting of the curves of the iron-carbon silicon system as a function of increasing content of manganese has been attempted; the curves previously determined had a manganese content of 0.20 per cent. To keep inside the limits of the manganese content of Thomas irons, the following proportions of manganese, 0.85, 1.15, 1.45 per cent, were chosen for the tests.

69. The desired manganese content was obtained by addition of 75 per cent ferromanganese.

*Ternary System Iron-Carbon-Manganese:*

70. Before undertaking this study, it was necessary to study, at least in a general way, the ternary system iron-carbon-manganese. Experimental difficulties prevented the study of this system as completely as could be wished. Heats were made in graphite crucibles. The manganese oxide formed, attacked the clay of the crucible, making carbon enter the bath in such a way that it was impossible to get more than 1.5 to 2.0 per cent manganese with less than 3.25 per cent carbon, although high manganese was obtained easily with 4.5 to 4.6 per cent carbon.

71. The following have been determined successively (Fig. 14):

(*a*) *a curve for 4.6 per cent carbon.* This is obviously in the hyper-eutectic region. The manganese decreases fluidity, a confirmation of the general law of fluidity.

(*b*) *a curve for 4.3 per cent carbon.* A progressive decrease in fluidity with increasing manganese was observed. This remains in the hyper-eutectic region and it is possible to conclude from this, that manganese, like phosphorus and silicon, decreases the eutectic concentration.

(*c*) *a curve for 4.0 per cent carbon.* The curve presents a more complicated form; increasing slowly followed by a sharp increase in fluidity at 1.20 per cent manganese. From the peak, at 1.20 per cent manganese, a sudden drop in fluidity occurs, followed then by a slow decrease. In this latter section, the curve is practically parallel to the two preceding ones. From this it is concluded that at 4 per cent carbon, the eutectic concentration is obtained at 1.20 per cent manganese, and that in

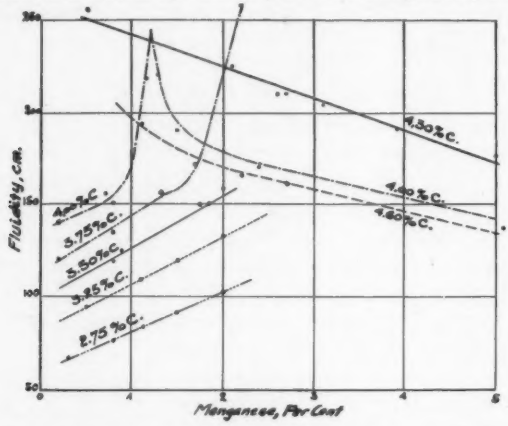


FIG. 14—FLUIDITY CURVES FOR IRONS CONTAINING VARYING PERCENTAGES OF MANGANESE AND CARBON. POURING TEMPERATURE 1450 DEGREES CENT. (2642 DEGREES FAHR.)

the proximity of this eutectic, manganese has a strong effect on the interval of solidification.

(*d*) *a curve at 3.75 per cent carbon.* This shows a slow increase in fluidity with the manganese content up to 1.70 per cent and after that a rapid increase. It was impossible to get more than 2.20 per cent manganese.

(*e*) *The curves at 3.50, 3.25, and 2.75 per cent carbon.* These show a slow increase of fluidity between 0 and 2 per cent manganese.

72. In conclusion, manganese does not show the anomaly of fluidity. Manganese increases fluidity in the hypo-eutectic region

and decreases it in the hyper-eutectic. This action of manganese is not strong, except in the neighborhood of the eutectic.

*Quaternary System Iron-Carbon-Silicon-Manganese:*

73. Sure that manganese does not have a new anomaly of fluidity, the study of the quaternary system iron-carbon-silicon-manganese was begun with carbon between the limits of 2.75-3.50 per cent; silicon between 0-4.0 per cent; and manganese between 0.20-1.50 per cent.

**Table 1**

VARIATION IN FLUIDITY OF AN IRON CONTAINING 3.50 PER CENT CARBON WITH VARYING SILICON CONTENTS

| Test Nos. | Carbon, Per Cent | Silicon, Per Cent | Manganese, Per Cent | Pouring Temperature—Degrees Cent.† | Length of Casting—Cm.* | Length of Casting at 1350 Degrees Cent.—Cm.* | Length of Casting at 3.5 Per Cent Carbon—Cm.* |
|---|---|---|---|---|---|---|---|
| 1 | 3.37 | 0.32 | 0.80 | 1400 | 151 | 131 | 140 |
| 2 | 3.55 | 0.34 | 0.85 | 1340 | 136 | 140 | 136 |
| 3 | 3.52 | 0.37 | 0.90 | 1390 | 145 | 129 | 128 |
| 4 | 3.59 | 0.39 | 0.90 | 1370 | 136 | 128 | 122 |
| 5 | 3.38 | 0.43 | 0.90 | 1380 | 128 | 116 | 125 |
| 6 | 3.40 | 0.47 | 0.87 | 1370 | 116 | 108 | 115 |
| 7 | 3.60 | 0.56 | 0.84 | 1420 | 160 | 132 | 125 |
| 8 | 3.65 | 0.62 | 0.82 | 1355 | 148 | 146 | 136 |
| 9 | 3.35 | 0.63 | 0.95 | 1400 | 140 | 120 | 131 |
| 10 | 3.35 | 0.63 | 0.95 | 1400 | 140 | 120 | 131 |
| 11 | 3.42 | 0.64 | 0.88 | 1385 | 140 | 126 | 131 |
| 12 | 3.40 | 0.75 | 0.90 | 1390 | 160 | 144 | 151 |
| 13 | 3.45 | 0.81 | 0.84 | 1410 | 175 | 151 | 155 |
| 14 | 3.62 | 0.84 | 0.75 | 1400 | 173 | 153 | 145 |
| 15 | 3.38 | 0.90 | 0.96 | 1380 | 149 | 137 | 146 |
| 16 | 3.38 | 0.97 | 0.80 | 1350 | 132 | 132 | 140 |
| 17 | 3.42 | 1.03 | 0.85 | 1420 | 155 | 127 | 133 |
| 18 | 3.40 | 1.20 | 0.84 | 1410 | 135 | 111 | 118 |
| 19 | 3.40 | 1.40 | 0.94 | 1400 | 130 | 110 | 117 |
| 20 | 3.56 | 1.50 | 0.85 | 1400 | 165 | 145 | 141 |
| 21 | 3.54 | 1.56 | 0.80 | 1380 | 160 | 148 | 137 |
| 22 | 3.43 | 1.80 | 0.80 | 1400 | 170 | 150 | 155 |
| 23 | 3.45 | 2.06 | 0.85 | 1350 | 155 | 155 | 159 |
| 24 | 3.63 | 2.40 | 0.86 | 1400 | 200 | 180 | 171 |
| 25 | 3.50 | 2.60 | 1.90 | 1390 | 190 | 174 | 174 |
| 26 | 3.68 | 3.00 | 0.84 | 1400 | 165 | 145 | 158 |
| 27 | 3.67 | 3.74 | 0.90 | 1410 | 116 | 92 | 104 |

†To convert degrees Cent. to degrees Fahr., multiply by 1.8 and add 32.
*To convert centimeters to inches, multiply by 0.3937.

74. To do this, the manganese was kept constant at 0.85, 1.15, and 1.45 per cent (the curves on the iron-carbon-silicon system were made with 0.20 per cent manganese) and the carbon and silicon contents were varied.

*(a) Irons Studied:*

In the study of the effect of manganese on fluidity, the following compositions were used:

## Table 2

### VARIATIONS IN FLUIDITY OF AN IRON CONTAINING 3.25 PER CENT CARBON WITH VARYING SILICON CONTENTS

| Test Nos. | Carbon, Per Cent | Silicon, Per Cent | Manganese, Per Cent | Pouring Temperature—Degrees Cent.† | Length of Casting—Cm.* | Length of Casting at 1350 Degrees Cent.—Cm.* | Length of Casting at 3.25 Per Cent Carbon—Cm.* |
|---|---|---|---|---|---|---|---|
| 1 | 3.25 | 0.20 | 0.85 | 1350 | 115 | 115 | 115 |
| 2 | 3.25 | 0.17 | 0.88 | 1350 | 105 | 105 | 105 |
| 3 | 3.25 | 0.33 | 0.79 | 1390 | 135 | 119 | 119 |
| 4 | 3.40 | 0.40 | 0.87 | 1370 | 116 | 108 | 98 |
| 5 | 3.35 | 0.43 | 0.65 | 1400 | 135 | 115 | 108 |
| 6 | 3.20 | 0.64 | 0.75 | 1380 | 125 | 113 | 117 |
| 7 | 3.20 | 0.64 | 0.70 | 1385 | 125 | 111 | 114 |
| 8 | 3.34 | 0.70 | 0.88 | 1400 | 135 | 115 | 109 |
| 9 | 3.36 | 0.73 | 0.95 | 1400 | 143 | 123 | 116 |
| 10 | 3.14 | 0.85 | 0.95 | 1350 | 114 | 114 | 122 |
| 11 | 3.20 | 1.03 | 0.84 | 1300 | 80 | 100 | 104 |
| 12 | 3.14 | 1.05 | 0.77 | 1400 | 122 | 102 | 109 |
| 13 | 3.26 | 1.18 | 0.95 | 1410 | 124 | 100 | 99 |
| 14 | 3.14 | 1.80 | 0.90 | 1375 | 133 | 123 | 131 |
| 15 | 3.26 | 2.06 | 0.85 | 1350 | 150 | 150 | 149 |
| 16 | 3.30 | 2.60 | 1.00 | 1380 | 176 | 164 | 160 |
| 17 | 3 16 | 2.74 | 0.95 | 1410 | 175 | 151 | 154 |
| 18 | 3.25 | 3.71 | 0.88 | 1400 | 210 | 190 | 190 |

†See footnote †, Table 1.
*See footnote *, Table 1.

## Table 3

### VARIATIONS IN FLUIDITY OF AN IRON CONTAINING 3.0 PER CENT CARBON WITH VARYING SILICON CONTENTS

| Test Nos. | Carbon, Per Cent | Silicon, Per Cent | Manganese, Per Cent | Pouring Temperature—Degrees Cent.†* | Length of Casting—Cm.* | Length of Casting at 1350 Degrees Cent.—Cm.* | Length of Casting at 3.0 Per Cent Carbon—Cm* |
|---|---|---|---|---|---|---|---|
| 1 | 3.10 | 0.20 | 0.92 | 1400 | 119 | 99 | 92 |
| 2 | 3.06 | 0.32 | 0.80 | 1350 | 110 | 110 | 106 |
| 3 | 2.94 | 0.35 | 0.80 | 1390 | 116 | 100 | 104 |
| 4 | 3.12 | 0.37 | 0.80 | 1350 | 100 | 100 | 92 |
| 5 | 2.86 | 0.47 | 0.80 | 1360 | 95 | 91 | 81 |
| 6 | 3.00 | 0.54 | 0.80 | 1350 | 91 | 91 | 91 |
| 7 | 3.12 | 0.84 | 0.95 | 1350 | 115 | 115 | 107 |
| 8 | 3.04 | 1.02 | 0.98 | 1390 | 125 | 109 | 106 |
| 9 | 3.14 | 1.05 | 0.80 | 1420 | 133 | 105 | 96 |
| 10 | 3.04 | 1.10 | 0.82 | 1370 | 106 | 98 | 95 |
| 11 | 3.10 | 1.20 | 0.84 | 1380 | 107 | 95 | 88 |
| 12 | 3.04 | 1.75 | 0.90 | 1375 | 128 | 118 | 115 |
| 13 | 3.14 | 1.80 | 0.90 | 1375 | 129 | 119 | 109 |
| 14 | 2.90 | 2.10 | 0.96 | 1380 | 130 | 118 | 125 |
| 15 | 3.05 | 2.13 | 0.80 | 1380 | 142 | 130 | 126 |
| 16 | 3.03 | 2.53 | 0.80 | 1370 | 148 | 140 | 138 |
| 17 | 3.00 | 2.82 | 0.90 | 1390 | 155 | 139 | 139 |
| 18 | 3.10 | 4.12 | 0.86 | 1390 | 197 | 181 | 174 |
| 19 | | | | | | | |

†See footnote †, Table 1.
*See footnote *, Table 2.

(1) 0.85 per cent manganese with 3.50, 3.25, 3.00 and 2.75 per cent carbon.

(2) 1.15 and 1.45 per cent manganese; in these two cases the extreme values of 3.50 and 2.75 per cent carbon were used.

75. Tests also were made on:

(1) A base iron with 0.2 per cent silicon.

(2) A base iron with over 0.75 per cent silicon.

**Table 4**

VARIATIONS IN FLUIDITY OF AN IRON CONTAINING 2.75 PER CENT CARBON WITH VARYING SILICON CONTENTS

| Test Nos. | Carbon, Per Cent | Silicon, Per Cent | Manganese, Per Cent | Pouring Temperature—Degrees Cent.† | Length of Casting—Cm.* | Length of Casting at 1350 Degrees Cent.—Cm.* | Length of Casting at 2.75 Per Cent Carbon—Cm.* |
|---|---|---|---|---|---|---|---|
| 1 | 2.52 | 0.15 | 0.86 | 1370 | 72 | 60 | 76 |
| 2 | 2.71 | 0.20 | 0.95 | 1370 | 83 | 71 | 74 |
| 3 | 2.73 | 0.27 | 0.90 | 1360 | 81 | 77 | 78 |
| 4 | 2.50 | 0.33 | 0.84 | 1335 | 67 | 73 | 90 |
| 5 | 2.70 | 0.35 | 0.84 | 1360 | 80 | 76 | 80 |
| 6 | 2.61 | 0.44 | 0.79 | 1420 | 95 | 67 | 77 |
| 7 | 2.82 | 0.48 | 0.88 | 1380 | 85 | 73 | 68 |
| 8 | 2.48 | 0.62 | 0.80 | 1350 | 65 | 65 | 84 |
| 9 | 2.86 | 0.67 | 0.80 | 1360 | 95 | 91 | 83 |
| 10 | 2.53 | 0.75 | 0.82 | 1390 | 98 | 82 | 98 |
| 11 | 2.75 | 0.80 | 0.84 | 1350 | 93 | 100 | 100 |
| 12 | 2.86 | 0.95 | 0.80 | 1330 | 88 | 96 | 88 |
| 13 | 2.86 | 0.99 | 0.80 | 1330 | 80 | 88 | 80 |
| 14 | 2.67 | 1.00 | 0.84 | 1380 | 85 | 73 | 78 |
| 15 | 2.75 | 1.15 | 0.85 | 1350 | 65 | 65 | 65 |
| 16 | 2.87 | 1.80 | 0.84 | 1400 | 127 | 107 | 98 |
| 17 | 2.70 | 2.00 | 0.90 | 1400 | 110 | 90 | 94 |
| 18 | 2.80 | 2.22 | 0.84 | 1425 | 145 | 115 | 112 |
| 19 | 2.81 | 2.40 | 0.76 | 1340 | 110 | 114 | 110 |
| 20 | 2.65 | 3.40 | 0.90 | 1420 | 145 | 117 | 124 |
| 21 | 2.86 | 3.80 | 0.88 | 1470 | 150 | 140 | 132 |
| 22 | 2.80 | 4.90 | 0.90 | 1400 | 155 | 155 | 151 |
| 23 | 2.80 | 5.20 | 0.90 | 1400 | 182 | 162 | 158 |

†See footnote †, Table 1.
*See footnote *, Table 1.

76. Very little information was available in the literature on the simultaneous effect of silicon and manganese on the properties of liquid metal. According to von Keil[11], manganese speeds up the dissociation of cementite in the liquid metal and for this reason crystallization occurs in the stable system.

*(b) Results:*

77. (1) *First case. Iron with 0.20 per cent silicon: (a) Study of the iron-carbon-silicon system with 0.85 per cent man-*

*ganese.* As previously stated, the variations in fluidity for increasing silicon contents, keeping the carbon constant at the following values, 3.50, 3.25, 3.00, and 2.75 per cent were determined. The results of these tests are reported in Tables 1, 2, 3 and 4.

78. To understand these, it is well to remember that all results were converted to a temperature of 1350 degrees Cent. (2462 degrees Fahr.)*, adopting a correction factor of 4 cm. per 10 degrees Cent. or 0.88 in. per 10 degrees Fahr., and at a fixed carbon content, adopting a correction factor previously determined as 7 cm. (2.76 in in.) for 0.1 per cent carbon. It has been assumed that these

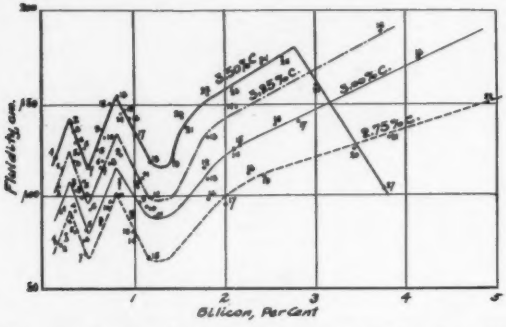


FIG. 15—FLUIDITY CURVES FOR IRONS CONTAINING 0.85 PER CENT MANGANESE AND 2.75, 3.00, 3.25 AND 3.50 PER CENT CARBON, WITH VARYING PERCENTAGES OF SILICON. POURED AT 1450 DEGREES CENT. (2642 DEGREES FAHR.)

corrections remained constant, regardless of the silicon and manganese; this can be done because of the relatively small limits within which the work was done. Plotting these results gave the curves shown in Fig. 15.

79. Although it would be premature to draw conclusions from these curves, the examination of this diagram permits the following observations to be made:

(1) The curves show the changes in fluidity as a function of increasing silicon, keeping the general contour observed in the study of the ternary system iron-carbon-silicon.

(2) When the manganese remains constant at 0.30 per cent, with 0.50 per cent silicon, the maximum and minimum correspond to the first anomaly of silicon.

(3) The second anomaly of silicon is always present; sometimes it is shifted slightly towards the higher silicon per-

* Temperature read on optical pyrometer corresponding to 1450 degrees Cent. (2642 degrees Fahr.) actual temperature.

centages. The maximum and minimum occur respectively (for 0.85 per cent manganese) at 0.80 and 1.25 per cent silicon, instead of 0.75 and 1.00 per cent observed in the study of the ternary system iron-carbon-silicon.

(4) The increase in fluidity after the second minimum is less sharp in the presence of 0.85 per cent manganese than with 0.20 per cent manganese; moreover, it is less accentuated as the carbon content is lower.

(5) Considering the curve with 3.50 per cent carbon, it will be noted that the eutectic maximum occurs at 2.80 per cent

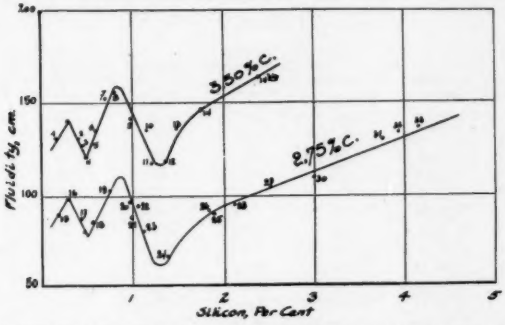


FIG. 16—FLUIDITY CURVES FOR IRONS CONTAINING 1.15 PER CENT MANGANESE AND 2.75 AND 3.50 PER CENT CARBON WITH VARYING PERCENTAGES OF SILICON. POURED AT A TEMPERATURE OF 1450 DEGREES CENT. (2642 DEGREES FAHR.)

**Table 5**

VARIATIONS IN FLUIDITY OF AN IRON CONTAINING 3.50 PER CENT CARBON AND 1.15 PER CENT MANGANESE WITH VARYING SILICON CONTENTS

| Test Nos. | Carbon, Per Cent | Silicon, Per Cent | Manganese, Per Cent | Pouring Temperature—Degrees Cent.† | Length of Casting—Cm.* | Length of Casting at 1350 Degrees Cent.—Cm.* | Length of Casting at 3.50 Per Cent Carbon—Cm.* |
|---|---|---|---|---|---|---|---|
| 1 | 3.10 | 0.15 | 1.20 | 1310 | 87 | 103 | 131 |
| 2 | 3.53 | 0.41 | 1.15 | 1380 | 145 | 133 | 131 |
| 3 | 3.51 | 0.45 | 1.15 | 1380 | 140 | 128 | 127 |
| 4 | 3.50 | 0.50 | 1.17 | 1360 | 124 | 120 | 120 |
| 5 | 3.49 | 0.55 | 1.13 | 1390 | 143 | 127 | 128 |
| 6 | 3.55 | 0.60 | 1.21 | 1370 | 147 | 139 | 135 |
| 7 | 3.33 | 0.70 | 1.14 | 1370 | 149 | 141 | 153 |
| 8 | 3.50 | 0.80 | 1.30 | 1360 | 160 | 156 | 156 |
| 9 | 3.20 | 0.98 | 1.25 | 1400 | 140 | 120 | 141 |
| 10 | 3.33 | 1.15 | 1.15 | 1380 | 136 | 124 | 136 |
| 11 | 3.40 | 1.20 | 1.21 | 1400 | 130 | 110 | 117 |
| 12 | 3.34 | 1.35 | 1.14 | 1390 | 122 | 106 | 117 |
| 13 | 3.45 | 1.46 | 1.14 | 1370 | 140 | 132 | 136 |
| 14 | 3.49 | 1.78 | 1.14 | 1400 | 165 | 145 | 146 |

†See footnote †, Table 1.
*See footnote *, Table 1.

silicon with 0.85 per cent manganese, while with 0.20 per cent manganese, it was produced at 3.00 per cent silicon.

80. (*b*) *Study of the Iron-Carbon-Silicon System with 1.15 per cent manganese:* For this part of the work, the two extreme values of carbon, 3.50 and 2.75 per cent, were taken. The experimental results are given in Tables 5 and 6. They permit the curves of Fig. 16 to be drawn.

**Table 6**

VARIATIONS IN FLUIDITY IN IRONS CONTAINING 2.75 PER CENT CARBON AND 1.15 PER CENT MANGANESE WITH VARYING SILICON CONTENTS

| Test Nos. | Carbon, Per Cent | Silicon, Per Cent | Manganese, Per Cent | Pouring Temperature—Degrees Cent.† | Length of Casting—Cm.* | Length of Casting at 1350 Degrees Cent.—Cm.* | Length of Casting at 2.75 Per Cent Carbon—Cm.* |
|---|---|---|---|---|---|---|---|
| 15 | 2.75 | 0.20 | 1.20 | 1350 | 90 | 90 | 90 |
| 16 | 2.78 | 0.30 | 1.15 | 1360 | 104 | 100 | 98 |
| 17 | 2.92 | 0.43 | 1.15 | 1375 | 110 | 100 | 88 |
| 18 | 2.78 | 0.45 | 1.15 | 1400 | 105 | 85 | 83 |
| 19 | 3.10 | 0.75 | 1.14 | 1370 | 135 | 127 | 103 |
| 20 | 3.05 | 0.92 | 1.27 | 1370 | 125 | 117 | 96 |
| 21 | 3.00 | 0.98 | 1.25 | 1400 | 126 | 106 | 89 |
| 22 | 2.82 | 1.01 | 1.20 | 1400 | 120 | 100 | 95 |
| 23 | 2.76 | 1.10 | 1.24 | 1375 | 90 | 80 | 80 |
| 24 | 2.75 | 1.40 | 1.15 | 1375 | 75 | 65 | 65 |
| 25 | 2.65 | 1.82 | 1.27 | 1420 | 114 | 86 | 93 |
| 26 | 3.06 | 1.84 | 1.08 | 1390 | 128 | 112 | 90 |
| 27 | 2.78 | 1.84 | 1.23 | 1420 | 120 | 92 | 90 |
| 28 | 2.75 | 2.00 | 1.13 | 1370 | 117 | 109 | 109 |
| 29 | 3.03 | 2.53 | 1.12 | 1390 | 140 | 124 | 105 |
| 30 | 2.96 | 2.99 | 1.10 | 1400 | 142 | 122 | 108 |
| 31 | 3.05 | 3.71 | 1.18 | 1400 | 174 | 154 | 133 |
| 32 | 3.05 | 3.94 | 1.12 | 1390 | 172 | 156 | 135 |
| 33 | 2.95 | 4.27 | 1.14 | 1400 | 170 | 150 | 136 |

†See footnote †, Table 1.
*See footnote *, Table 1.

81. A study of these curves suggests that the general contour of the curves always remains the same, with the first anomaly of silicon fixed between 0.30 and 0.50 per cent silicon, the second anomaly shifting slightly toward the higher values of silicon. These occur, with 1.15 per cent manganese, between 0.85 per cent and 1.30 per cent silicon; on the other hand, the difference between the maximum and minimum values increases in proportion to the increase of manganese concentration.

82. (*c*) *Study of the Iron-Carbon-Silicon System with 1.45 per cent Manganese:* As in the former case, carbon contents were limited to 3.50 and 2.75 per cent. The curves of Fig. 17, drawn

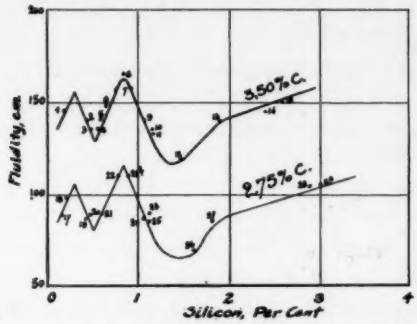


FIG. 17—FLUIDITY CURVES OF IRONS CONTAINING 1.45 PER CENT MANGANESE AND 2.75 AND 3.50 PER CENT CARBON WITH VARYING PERCENTAGES OF SILICON. POURED AT A TEMPERATURE OF 1450 DEGREES CENT. (2642 DEGREES FAHR.)

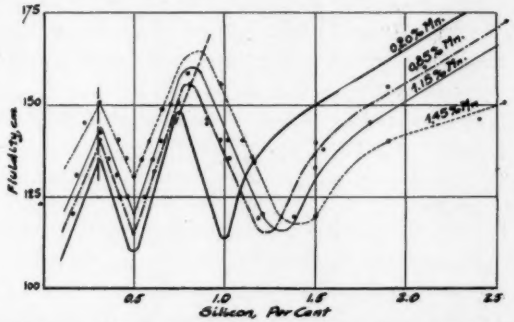


FIG. 18—FLUIDITY CURVES FOR IRONS CONTAINING 3.50 PER CENT CARBON, 0.20, 0.85, 1.15 AND 1.45 PER CENT MANGANESE WITH VARYING PERCENTAGES OF SILICON POURED AT 1450 DEGREES CENT. (2642 DEGREES FAHR.) SHOWING SIMULTANEOUS EFFECT OF MANGANESE AND SILICON,

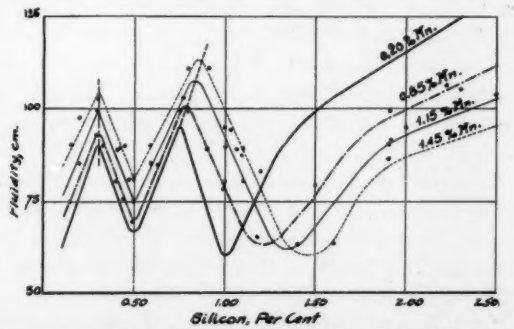


FIG. 19—FLUIDITY CURVES FOR IRONS CONTAINING 2.75 PER CENT CARBON, 0.20, 0.85, 1.15, AND 1.45 PER CENT MANGANESE POURED AT 1450 DEGREES CENT. (2642 DEGREES FAHR.) SHOWING SIMULTANEOUS EFFECT OF MANGANESE AND SILICON.

with the help of the results shown in Tables 7 and 8, confirm again the former conclusions that:

(1) the first anomaly appears between 0.30 and 0.50 per cent silicon

(2) the second anomaly appears between 0.80 and 1.40 per cent silicon

(3) the difference between the maximum and minimum values for fluidity in the second anomaly are further increased.

83. (*d*) *Study of the Quaternary System Iron-Silicon-Manganese-Carbon:* If the fluidity curves corresponding to the same carbon content, but with manganese increasing from 0.20 to 0.85 to 1.15 and to 1.45 per cent are plotted on the same chart, an idea of the simultaneous effect of manganese and of silicon on the fluidity of the iron-carbon alloy with a constant carbon content can be obtained. Figs. 18 and 19 show the various curves obtained with different manganese contents, for the extreme carbon values of 3.50 and 2.75 per cent respectively.

84. The examination of these two diagrams shows some very interesting facts. Up to 0.75 per cent, the curves are practically parallel, showing a slow, progressive increase in fluidity as a function of manganese, no matter what the silicon. On the contrary, because of the shifting of the second anomaly, that for silicon higher than 0.75 per cent, the increase in fluidity due to manganese is a function of the silicon content of the metal.

85. On the other hand, because of the displacement of the second anomaly (which appears at 1.00 per cent silicon for 0.20 per cent manganese and at 1.40 per cent silicon for 1.45 per cent manganese), there follows an interpretation of these different curves. Between 1.00 and 1.40 per cent silicon, for each silicon content, there is a critical content of manganese, beyond which it increases fluidity and below which it decreases it. However, it should be said that the changes in fluidity due to manganese are not very important.

86. This part of the work can be concluded in the following manner: Manganese does not seem to have a very strong effect on the fluidity of iron-carbon-silicon alloys. However, the importance of its effect, and the nature of that effect, are essentially functions of the carbon and silicon content of the metal.

87. (*2*) *Second Case—Base Iron with Silicon over 0.75 per cent:* It has been assumed, in basing conclusions on the study of the ternary system iron-carbon-silicon, that the silicon content of the

**Table 7**

VARIATIONS IN FLUIDITY IN IRONS CONTAINING 3.50 PER CENT CARBON AND 1.45 PER CENT MANGANESE WITH VARYING SILICON CONTENTS

| Test Nos. | Carbon, Per Cent | Silicon, Per Cent | Manganese, Per Cent | Pouring Temperature—Degrees Cent.† | Length of Casting—Cm.* | Length of Casting at 1350 Degrees Cent.—Cm.* | Length of Casting at 3.50 Per Cent Carbon—Cm.* |
|---|---|---|---|---|---|---|---|
| 1 | 3.50 | 0.20 | 1.40 | 1360 | 136 | 132 | 146 |
| 2 | 3.30 | 0.42 | 1.40 | 1370 | 134 | 126 | 140 |
| 3 | 3.27 | 0.45 | 1.62 | 1360 | 126 | 122 | 138 |
| 4 | 3.75 | 0.56 | 1.40 | 1410 | 176 | 152 | 135 |
| 5 | 3.50 | 0.59 | 1.40 | 1390 | 158 | 142 | 142 |
| 6 | 3.50 | 0.65 | 1.38 | 1350 | 147 | 147 | 147 |
| 7 | 3.30 | 0.95 | 1.42 | 1380 | 154 | 142 | 156 |
| 8 | 3.50 | 0.88 | 1.58 | 1350 | 165 | 165 | 165 |
| 9 | 3.50 | 1.05 | 1.60 | 1370 | 148 | 140 | 140 |
| 10 | 3.30 | 1.14 | 1.35 | 1390 | 135 | 119 | 133 |
| 11 | 3.70 | 1.13 | 1.35 | 1390 | 165 | 149 | 135 |
| 12 | 3.40 | 1.48 | 1.49 | 1385 | 125 | 111 | 118 |
| 13 | 3.15 | 1.80 | 1.40 | 1400 | 135 | 115 | 140 |
| 14 | 3.54 | 2.40 | 1.50 | 1380 | 160 | 148 | 145 |
| 15 | 3.50 | 2.55 | 1.40 | 1360 | 158 | 152 | 152 |

†See footnote †, Table 1.
*See footnote *, Table 1.

**Table 8**

VARIATIONS IN FLUIDITY IN IRONS CONTAINING 2.75 PER CENT CARBON AND 1.45 PER CENT MANGANESE WITH VARYING SILICON CONTENTS

| Test Nos. | Carbon, Per Cent | Silicon, Per Cent | Manganese, Per Cent | Pouring Temperature—Degrees Cent.† | Length of Casting—Cm.* | Length of Casting at 1350 Degrees Cent.—Cm.* | Length of Casting at 2.75 Per Cent Carbon—Cm.* |
|---|---|---|---|---|---|---|---|
| 17 | 3.04 | 0.15 | 1.40 | 1360 | 113 | 109 | 89 |
| 18 | 2.75 | 0.20 | 1.40 | 1350 | 97 | 97 | 97 |
| 19 | 3.00 | 0.42 | 1.39 | 1360 | 109 | 105 | 88 |
| 20 | 3.10 | 0.44 | 1.40 | 1370 | 120 | 112 | 88 |
| 21 | 3.00 | 0.58 | 1.40 | 1390 | 123 | 107 | 90 |
| 22 | 2.75 | 0.77 | 1.40 | 1350 | 110 | 110 | 110 |
| 22 | 2.75 | 0.93 | 1.40 | 1360 | 114 | 110 | 110 |
| 23 | 2.95 | 1.10 | 1.50 | 1370 | 110 | 102 | 88 |
| 24 | 3.00 | 1.05 | 1.52 | 1390 | 121 | 105 | 87 |
| 25 | 2.95 | 1.10 | 1.38 | 1300 | 80 | 100 | 86 |
| 26 | 2.90 | 1.60 | 1.55 | 1340 | 76 | 80 | 70 |
| 27 | 3.15 | 1.82 | 1.40 | 1400 | 135 | 115 | 87 |
| 28 | 2.97 | 2.90 | 1.40 | 1380 | 137 | 125 | 119 |
| 29 | 2.93 | 3.00 | 1.60 | 1340 | 115 | 119 | 106 |

†See footnote †, Table 1.
*See footnote *, Table 1.

base iron had no influence whatsoever on the existence and position of the first anomaly. The position of curves for silicon contents over 0.80 per cent were studied. In this section of the work research has been limited to the two extreme carbon percentages, 3.50

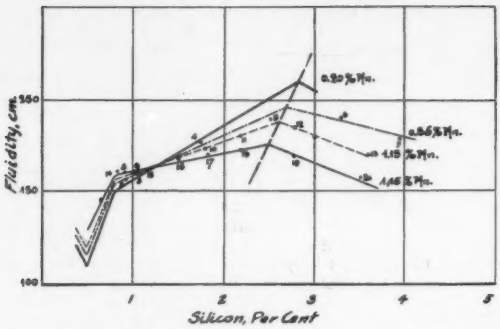


FIG. 20—CURVES OF IRONS CONTAINING 0.20, 0.80, 1.15 AND 1.45 PER CENT MANGANESE AND 3.50 PER CENT CARBON WITH VARYING PERCENTAGES OF SILICON SHOWING THE DISPLACEMENT OF THE EUTECTIC POINTS. IRONS WERE POURED AT 1450 DEGREES CENT. (2642 DEGREES FAHR.)

**Table 9**

VARIATIONS IN FLUIDITY IN IRONS CONTAINING 3.50 PER CENT CARBON AND DEFINITE PERCENTAGES OF MANGANESE, WITH VARYING SILICON CONTENTS

| Test Nos. | Carbon, Per Cent | Silicon, Per Cent | Manganese, Per Cent | Pouring Temperature—Degrees Cent.† | Length of Casting—Cm.* | Length of Casting at 1350 Degrees Cent.—Cm.* | Length of Casting at 3.50 Per Cent Carbon—Cm.* |
|---|---|---|---|---|---|---|---|
| **Irons Containing 0.80 Per Cent Manganese** | | | | | | | |
| 1 | 3.23 | 0.66 | 0.80 | 1340 | 124 | 128 | 146 |
| 2 | 3.10 | 0.95 | 0.96 | 1390 | 145 | 129 | 157 |
| 3 | 3.50 | 1.01 | 0.84 | 1400 | 180 | 160 | 160 |
| 4 | 3.26 | 1.78 | 0.76 | 1350 | 160 | 160 | 177 |
| 5 | 3.33 | 2.45 | 0.77 | 1390 | 190 | 176 | 187 |
| 6 | 3.55 | 3.29 | 0.80 | 1375 | 205 | 195 | 191 |
| 7 | 3.48 | 3.95 | 0.84 | 1390 | 195 | 199 | 179 |
| **Irons Containing 1.15 Per Cent Manganese** | | | | | | | |
| 8 | 3.50 | 0.95 | 1.20 | 1370 | 168 | 160 | 160 |
| 9 | 3.42 | 1.01 | 1.15 | 1400 | 175 | 165 | 161 |
| 10 | 3.35 | 1.80 | 1.17 | 1400 | 185 | 165 | 175 |
| 11 | 3.38 | 2.20 | 1.20 | 1340 | 170 | 174 | 182 |
| 12 | 3.50 | 2.80 | 1.15 | 1350 | 185 | 185 | 185 |
| 13 | 3.52 | 3.50 | 1.12 | 1370 | 178 | 170 | 170 |
| **Irons Containing 1.45 Per Cent Manganese** | | | | | | | |
| 14 | 3.50 | 0.83 | 1.40 | 1350 | 163 | 163 | 163 |
| 15 | 3.40 | 0.90 | 1.42 | 1370 | 162 | 154 | 161 |
| 16 | 3.45 | 1.10 | 1.45 | 1380 | 171 | 159 | 163 |
| 17 | 3.38 | 1.50 | 1.39 | 1375 | 172 | 162 | 170 |
| 18 | 3.65 | 1.84 | 1.40 | 1370 | 187 | 179 | 179 |
| 19 | 3.57 | 2.20 | 1.42 | 1390 | 192 | 176 | 171 |
| 20 | 3.47 | 2.82 | 1.40 | 1400 | 191 | 171 | 169 |
| 21 | 3.40 | 3.53 | 1.48 | 1400 | 184 | 164 | 157 |
| 22 | 3.50 | 3.90 | 1.50 | 1380 | 170 | 158 | 158 |

†See footnote †, Table 1.
*See footnote *, Table 1.

and 2.75 per cent. With these contents, manganese percentages of 0.20, 0.85, 1.15 and 1.45 per cent were used.

88. (*a*) *Iron-Carbon-Silicon-Manganese Alloys with 3.50 per cent Carbon:* The results obtained from tests on fluidity, shown in Table 9, permit the curves in Fig. 20 to be traced. Examination of these curves suggest the following:

(1) The conclusions from the study of the ternary system iron-carbon-silicon, namely that the second anomaly appears and disappears following the silicon content in the base iron, are confirmed.

(2) Manganese lessens the influence of silicon on fluidity, in proportion as the percentage of manganese increases, the curves showing the variation of fluidity as a function of silicon content, fall toward the axis of the abscissa. Using the same interpretation of curves as previously, and if, up to 1.30 per cent silicon, the manganese increases slightly the fluidity for the higher percentages, it decreases fluidity as the silicon content of the metal is larger.

(3) Manganese slightly displaces the eutectic points with low silicon present. In the presence of 0.20 per cent manganese, the eutectic maximum appears around 2.8 per cent silicon; for 0.80 per cent manganese, it passes to 2.7 per cent silicon; at 1.15 per cent manganese, it is 2.6 per cent silicon; and at 1.45 per cent manganese, appears at 2.5 per cent silicon.

89. (*b*) *Iron-Carbon-Silicon-Manganese Alloys with 2.75 per cent Carbon:* The diagram in Fig. 21, made with the help of the experimental results shown in Table 10, gives rise to the following considerations: (1), Disappearance of the second anomaly; and (2), decrease in the increase of fluidity due to silicon with increasing manganese content. The curves sink closer to the abscissa as the manganese percentage is raised. This phenomenon is more accentuated for this carbon content than for 3.50 per cent carbon; in this way, it may be stated that when the silicon content is over 1.3 per cent, the manganese diminishes the fluidity more as the carbon content becomes less. However, this influence is not important.

90. The study of fluidity in the quaternary system iron-carbon-silicon-manganese with the limits 0.20 to 1.50 per cent manganese, 2.75 to 3.50 per cent carbon, and 0 to 4.00 per cent silicon brings out the following conclusions:

(1) Within the limits studied, manganese does not seem to have much influence on fluidity. The direction of its in-

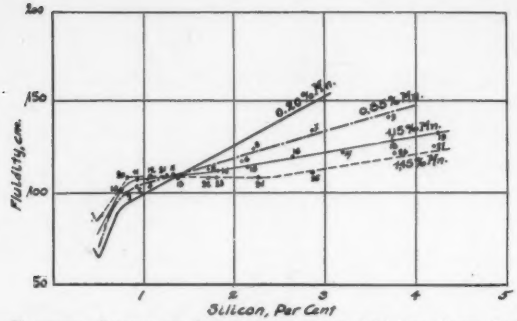


FIG. 21—FLUIDITY CURVES OF IRONS CONTAINING 2.75 PER CENT CARBON AND 0.20, 0.85, 1.15 AND 1.45 PER CENT MANGANESE WITH VARYING PERCENTAGES OF SILICON POURED AT 1450 DEGREES CENT. (2642 DEGREES FAHR.)

## Table 10

### VARIATIONS IN FLUIDITY OF IRONS CONTAINING 2.75 PER CENT CARBON AND DEFINITE PERCENTAGES OF MANGANESE WITH VARYING SILICON CONTENTS

| Test Nos. | Carbon, Per Cent | Silicon, Per Cent | Manganese, Per Cent | Pouring Temperature—Degrees Cent.† | Length of Casting—Cm.* | Length of Casting at 1350 Degrees Cent.—Cm.* | Length of Casting at 2.75 Per Cent Carbon—Cm.* |
|---|---|---|---|---|---|---|---|
| **Irons Containing 0.80 Per Cent Manganese** | | | | | | | |
| 1 | 2.75 | 0.80 | 0.85 | 1370 | 108 | 100 | 100 |
| 2 | 2.74 | 0.90 | 0.91 | 1340 | 98 | 102 | 103 |
| 3 | 2.80 | 1.10 | 0.80 | 1360 | 115 | 111 | 107 |
| 4 | 2.90 | 1.32 | 0.78 | 1390 | 136 | 120 | 110 |
| 5 | 3.00 | 1.70 | 0.82 | 1375 | 140 | 130 | 113 |
| 6 | 3.05 | 2.06 | 0.80 | 1380 | 150 | 138 | 117 |
| 7 | 2.95 | 2.85 | 0.80 | 1390 | 165 | 149 | 135 |
| 8 | 2.68 | 2.20 | 0.82 | 1400 | 140 | 120 | 124 |
| 9 | 2.75 | 3.72 | 0.80 | 1410 | 170 | 146 | 146 |
| **Irons Containing 1.15 Per Cent Manganese** | | | | | | | |
| 10 | 2.75 | 0.80 | 1.15 | 1350 | 104 | 104 | 104 |
| 11 | 3.00 | 0.95 | 1.17 | 1360 | 130 | 126 | 109 |
| 12 | 2.85 | 1.10 | 1.20 | 1360 | 121 | 117 | 110 |
| 13 | 3.00 | 1.37 | 1.14 | 1375 | 135 | 125 | 108 |
| 14 | 2.90 | 1.80 | 1.18 | 1370 | 130 | 122 | 112 |
| 15 | 2.80 | 2.12 | 1.17 | 1390 | 135 | 119 | 115 |
| 16 | 2.68 | 2.63 | 1.15 | 1340 | 112 | 116 | 121 |
| 17 | 2.75 | 3.20 | 1.18 | 1340 | 120 | 124 | 124 |
| 18 | 3.07 | 3.71 | 1.18 | 1400 | 173 | 153 | 131 |
| 19 | 2.95 | 4.27 | 1.14 | 1400 | 170 | 150 | 136 |
| **Irons Containing 1.45 Per Cent Manganese** | | | | | | | |
| 20 | 2.75 | 0.81 | 1.50 | 1350 | 108 | 108 | 108 |
| 21 | 2.70 | 1.24 | 1.40 | 1370 | 113 | 105 | 109 |
| 22 | 3.04 | 1.61 | 1.42 | 1340 | 124 | 128 | 108 |
| 23 | 2.90 | 1.69 | 1.45 | 1360 | 124 | 120 | 110 |
| 24 | 2.85 | 2.26 | 1.41 | 1380 | 128 | 116 | 109 |
| 25 | 2.85 | 2.86 | 1.43 | 1360 | 122 | 118 | 111 |
| 26 | 2.85 | 3.76 | 1.44 | 1390 | 147 | 131 | 124 |
| 27 | 2.85 | 4.17 | 1.44 | 1400 | 155 | 135 | 128 |

†See footnote †, Table 1.
*See footnote *, Table 1.

fluence, as well as its strength, are essentially functions of the carbon and silicon contents of the base metal.

(2) Manganese shifts the eutectic points; for a given carbon, it slightly decreases the amount of silicon necessary for the eutectic concentration with that carbon.

(3) If we judge by the shape of the curves as well as by the displacement of the eutectic maxima, it seems that manganese increases the interval of solidification, unless the decrease of fluidity observed could be caused by the partial dissociation of the cementite in the liquid phase.[11]

(4) With manganese at 0.30 per cent and silicon at 0.50 per cent, the maximum and minimum of fluidity correspond to the first anomaly.

(5) When the base iron has a content of 0.20 per cent silicon, the second anomaly is present regardless of the manganese percentage. However, it is slightly moved and accentuated. This double displacement shows that, for silicon contents over 1.00 per cent, a critical content of manganese exists beyond which it lessens fluidity, before which it increases it.

(6) Manganese beyond 1.00 per cent silicon decreases the action of silicon on fluidity, which is more marked as the carbon content is lower.

(7) When the base iron has more than 0.75 per cent silicon, the second anomaly disappears, confirming the conclusion drawn from the study of the ternary system iron-carbon-silicon. In all six conclusions, there is a critical silicon content, approximately 1.30 per cent, above which manganese diminishes fluidity.

### SIMULTANEOUS INFLUENCE OF SILICON AND PHOSPHORUS

91. The quaternary system iron-carbon-silicon-phosphorus has been studied by Keil and Mitchke[12]. These authors have found, using both micrographic analysis and thermo-electric studies, the position of the line of deposition of the binary eutectic of the iron-carbon-phosphorus system in the presence of 1.2, 1.8, and 2.8 per cent silicon.

92. Fig. 22 summarizes the results of these authors. The conclusions drawn are as follows: The effects of silicon and of phosphorus on the displacement of the eutectic are not additive as certain people have believed. The law is much more complicated. The

displacement of the eutectic by silicon is a function of both carbon and phosphorus.

93. This part of the research is not yet finished. It was thought that it would be interesting to give the first results. Tests have shown the simultaneous effect of silicon and phosphorus for a carbon content of 3.00 per cent, the first iron studied having 0.20 per cent silicon and the second, 0.75 per cent silicon.

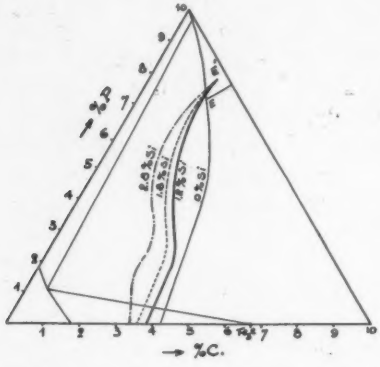


FIG. 22—THE QUATERNARY SYSTEM IRON-CARBON-SILICON-PHOSPHORUS, ACCORDING TO VON KEIL AND MITCHKE.

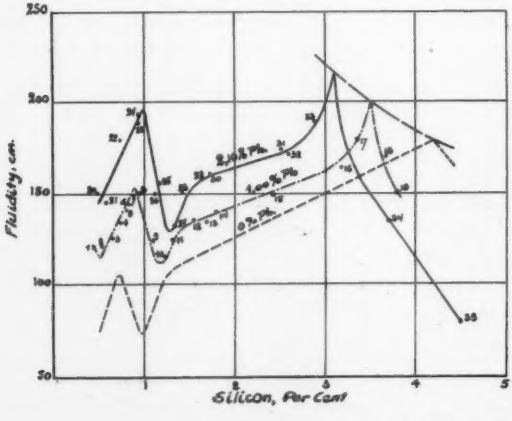


FIG. 23—FLUIDITY CURVES OF AN IRON CONTAINING 3.00 PER CENT CARBON, 1.00, AND 2.10 PER CENT PHOSPHORUS AND VARYING PERCENTAGES OF SILICON POURED AT 1450 DEGREES CENT. (2642 DEGREES FAHR.)

94. The desired phosphorus content was obtained with additions of 22 per cent ferro-phosphorus. The silicon content present in that alloy was such that it was impossible to secure silicon contents under 0.50 per cent, even when the base iron had only 0.20 per cent silicon. Therefore, in making these synthetic irons, it was not possible to study the influence of phosphorus on the position and size of the first anomaly of silicon.

**Table 11**

VARIATIONS IN FLUIDITY OF IRONS CONTAINING 3.0 PER CENT CARBON AND DEFINITE PERCENTAGES OF PHOSPHORUS WITH VARYING SILICON CONTENTS

| Test Nos. | Carbon. Per Cent | Silicon. Per Cent | Phosphorus. Per Cent | Pouring Temperature—Degrees Cent.† | Length of Casting—Cm.* | Length of Casting at 1350 Degrees Cent.—Cm.* | Length of Casting at 3.0 Per Cent Carbon—Cm.* |
|---|---|---|---|---|---|---|---|
| Irons Containing 1.0 Per Cent Phosphorus | | | | | | | |
| 1 | 3.01 | 0.47 | 1.00 | 1300 | 102 | 122 | 122 |
| 2 | 3.00 | 0.54 | 3.08 | 1380 | 132 | 120 | 120 |
| 3 | 3.05 | 0.68 | 1.03 | 1380 | 140 | 128 | 125 |
| 4 | 3.01 | 0.75 | 1.08 | 1375 | 145 | 135 | 135 |
| 5 | 3.00 | 0.80 | 1.08 | 1410 | 165 | 141 | 141 |
| 6 | 3.01 | 0.86 | 1.05 | 1350 | 145 | 145 | 144 |
| 7 | 3.09 | 0.95 | 1.03 | 1360 | 160 | 154 | 148 |
| 8 | 3.46 | 0.90 | 0.95 | 1300 | 160 | 180 | 148 |
| 9 | 3.38 | 1.11 | 1.01 | 1375 | 160 | 150 | 124 |
| 10 | 3.00 | 1.16 | 1.00 | 1340 | 110 | 114 | 114 |
| 11 | 2.90 | 1.32 | 1.03 | 1400 | 140 | 120 | 127 |
| 12 | 3.09 | 1.52 | 0.95 | 1370 | 150 | 142 | 135 |
| 13 | 3.39 | 1.73 | 1.00 | 1370 | 170 | 162 | 135 |
| 14 | 2.90 | 1.80 | 0.95 | 1350 | 135 | 135 | 142 |
| 15 | 2.66 | 2.37 | 0.98 | 1400 | 145 | 125 | 150 |
| 16 | 2.90 | 3.25 | 0.98 | 1390 | 173 | 157 | 164 |
| 17 | 2.66 | 3.31 | 0.99 | 1340 | 151 | 154 | 179 |
| 18 | 2.76 | 3.63 | 1.00 | 1400 | 175 | 155 | 172 |
| 19 | 2.96 | 3.83 | 0.97 | 1425 | 180 | 150 | 153 |
| Irons Containing 2.10 Per Cent Phosphorus | | | | | | | |
| 20 | 2.78 | 0.52 | 2.10 | 1400 | 154 | 134 | 149 |
| 21 | 2.66 | 0.62 | 2.08 | 1340 | 116 | 120 | 144 |
| 22 | 2.55 | 0.73 | 2.07 | 1350 | 140 | 140 | 172 |
| 23 | 3.00 | 0.90 | 2.10 | 1390 | 195 | 179 | 179 |
| 24 | 2.75 | 0.90 | 2.20 | 1375 | 175 | 165 | 182 |
| 25 | 2.67 | 1.13 | 2.07 | 1380 | 145 | 133 | 156 |
| 26 | 2.86 | 1.11 | 2.20 | 1300 | 120 | 140 | 150 |
| 27 | 2.67 | 1.37 | 1.95 | 1375 | 120 | 110 | 133 |
| 28 | 2.80 | 1.40 | 2.13 | 1380 | 151 | 139 | 153 |
| 29 | 2.85 | 1.64 | 2.01 | 1400 | 170 | 150 | 160 |
| 30 | 2.85 | 1.73 | 2.10 | 1380 | 161 | 149 | 160 |
| 31 | 2.80 | 2.55 | 2.01 | 1340 | 160 | 164 | 178 |
| 32 | 3.00 | 2.61 | 2.01 | 1400 | 193 | 173 | 173 |
| 33 | 3.00 | 2.90 | 2.10 | 1350 | 190 | 190 | 190 |
| 34 | 3.11 | 3.60 | 2.10 | 1340 | 125 | 129 | 136 |
| 35 | 3.13 | 4.58 | 2.25 | 1360 | 98 | 74 | 81 |

†See footnote †, Table 1.
*See footnote *, Table 1.

95. Fig. 23 summarizes results obtained with the base iron containing 0.20 per cent silicon. The results which enabled these curves to be drawn are given in Table 11. Three different curves are shown in Fig. 23, the first at 0 per cent phosphorus, taken from the study of the ternary system iron-carbon-silicon; the second with 1 per cent phosphorus and the third with 2.10 per cent phosphorus.

96. Examination of this chart brings out the following conclusions:

(a) Phosphorus increases fluidity of ternary alloys iron-carbon-silicon, regardless of the carbon and silicon in the mix (in the hypo-eutectic region of the chart).

(b) For high silicon contents, phosphorus moves the maxima and minima corresponding to the second anomaly of silicon, as is shown in the following:

| Phosphorus Per Cent | Silicon Per Cent Maximum | Silicon Per Cent Minimum |
|---|---|---|
| 0 | 0.75 | 1.00 |
| 1.0 | 0.90 | 1.15 |
| 2.1 | 1.00 | 1.30 |

(c) Beyond the minimum of the second anomaly, the change in fluidity as a function of silicon keeps the same general shape as in the absence of phosphorus. Always in the vicinity of the eutectic, a sharp change in fluidity is noticed, corresponding to the presence of the ternary eutectic. This sudden increase in fluidity is explained by the lowering of the temperature of solidification and by lessening the interval of secondary crystallization.

(d) Phosphorus lowers the amount of silicon necessary for the eutectic. This goes from 4.2 per cent silicon with 0 per cent phosphorus, to 3.5 per cent silicon for 1.0 per cent phosphorus, and 3.05 per cent silicon for 2.10 per cent phosphorus. These tests were made with 3.0 per cent carbon.

(e) Phosphorus diminishes fluidity in the hyper-eutectic region.

97. If the base iron has a silicon content of 0.75 per cent, the curves show the simultaneous influence of silicon and phosphorus on the fluidity of an iron with 3.0 per cent carbon, taking the shape shown in Fig. 24; the experimental results from which these curves were drawn are given in Table 12.

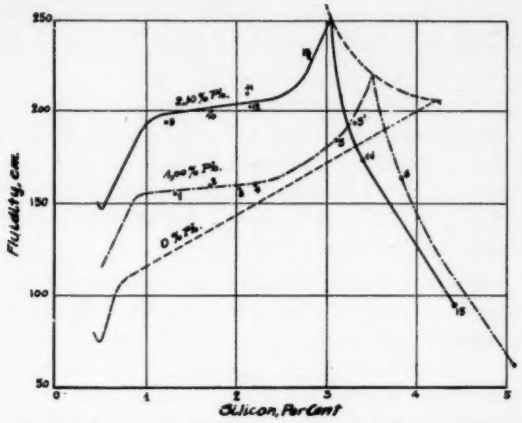


FIG. 24—FLUIDITY CURVES OF IRONS CONTAINING 3.00 PER CENT CARBON, 0, 1.00, AND 2.10 PER CENT PHOSPHORUS AND VARYING PERCENTAGES OF SILICON POURED AT 1450 DEGREES CENT. (2642 DEGREES FAHR.).

**Table 12**

VARIATION IN FLUIDITY OF IRONS CONTAINING 3.0 PER CENT CARBON AND DEFINITE PERCENTAGES OF PHOSPHORUS WITH VARYING SILICON CONTENTS

| Test Nos. | Carbon, Per Cent | Silicon, Per Cent | Phosphorus, Per Cent | Pouring Temperature—Degrees Cent.† | Length of Casting—Cm.* | Length of Casting at 1350 Degrees Cent.—Cm.* | Length of Casting at 3.0 Per Cent Carbon—Cm.* |
|---|---|---|---|---|---|---|---|
| Irons Containing 1.0 Per Cent Phosphorus | | | | | | | |
| 1 | 3.00 | 1.35 | 1.00 | 1380 | 168 | 156 | 156 |
| 2 | 3.40 | 1.76 | 1.00 | 1390 | 200 | 186 | 158 |
| 3 | 3.50 | 2.03 | 1.06 | 1380 | 204 | 192 | 157 |
| 4 | 3.15 | 2.24 | 1.00 | 1400 | 190 | 170 | 160 |
| 5 | 3.00 | 3.30 | 1.00 | 1370 | 203 | 195 | 195 |
| 6 | 3.00 | 3.82 | 1.07 | 1330 | 155 | 163 | 163 |
| 7 | 3.13 | 4.20 | 1.01 | 1380 | 113 | 101 | 111 |
| 8 | 3.17 | 5.13 | 1.03 | 1425 | 80 | 50 | 62 |
| Irons Containing 2.10 Per Cent Phosphorus | | | | | | | |
| 9 | 3.00 | 1.20 | 2.10 | 1350 | 195 | 195 | 195 |
| 10 | 3.20 | 1.69 | 2.10 | 1350 | 215 | 215 | 201 |
| 11 | 3.00 | 2.33 | 2.05 | 1350 | 210 | 210 | 210 |
| 12 | 2.85 | 2.35 | 2.07 | 1350 | 195 | 195 | 205 |
| 13 | 3.01 | 2.80 | 2.11 | 1340 | 226 | 230 | 229 |
| 14 | 3.00 | 3.30 | 2.09 | 1365 | 180 | 174 | 174 |
| 15 | 3.00 | 4.24 | 2.13 | 1400 | 95 | 95 | 95 |

†See footnote †, Table 1.
*See footnote *, Table 1.

98. This chart confirms all earlier conclusions: (a) The disappearance of the second anomaly; (b) the favorable influence of phosphorus on fluidity of iron-carbon-silicon alloys in the hypo-eutectic region; and (c) the displacement toward lower content of

silicon of the eutectic points when the phosphorus is increased. These come at the same content of silicon no matter what the concentration in the base iron.

99. It has been stated previously that with the amount of silicon in the ferro-phosphorus, sufficiently low content of silicon to find the first anomaly could not be obtained in these synthetic irons. Since the first anomaly always is present, and remains between 0.30 and 0.50 per cent silicon, the second series of results were judged as follows:

100. The superintendent of a large foundry in the Liege district wanted to confirm results and anomalies given in this paper, using an industrial iron instead of the synthetic irons. He used a forge pig iron from the Thomas process. This iron had an initial silicon content below 0.50 per cent. He has been kind enough to give the results obtained, shown in Table 13. The lengths obtained are the average of three tests conducted at 1250 degrees Cent. (2282 degrees Fahr.) read with optical pyrometer, (really 1350 degrees Cent. or 2462 degrees Fahr.). All results have been calculated to 3.0 per cent carbon, using the correction factor previously adopted (7 cm. or 2.76 in. for 0.10 per cent carbon).

101. The manganese content varied in most of these tests between 0.65 and 1.25 per cent manganese, because of the slight influence of manganese on fluidity, this variation is negligible. The sulphur content of the iron used was around 0.05 and 0.07 per cent. The phosphorus is on an average, about 1.80 per cent.

102. With the help of these results, a curve, showing the variations of fluidity as a function of silicon, can be drawn for an industrial iron whose original silicon concentration was less than 0.50 per cent and whose analysis was carbon, 3.0 per cent; phosphorus, approximately 1.80 per cent; manganese, 1.00 per cent; and sulphur, 0.06 per cent.

103. Even though these tests lack the precision of the earlier tests, because the concentrations of certain elements like manganese and sulphur were not constant, these results permit a curve (Fig. 25) to be drawn whose shape shows the general tendency of the curves obtained with synthetic irons. This chart is most interesting, because it shows:

(1) The anomalies are practical facts, and not a speculation of a theoretical scientist.

(2) They confirm the fact that the second anomaly ap-

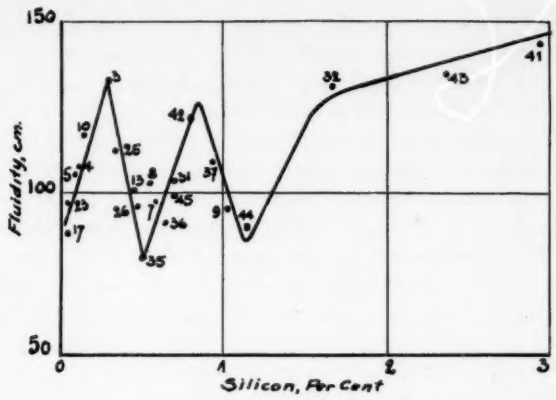


FIG. 25—FLUIDITY CURVE FOR A COMMERCIAL IRON. THE SHAPE OF THE CURVE SHOWS THE GENERAL TENDENCY OF CURVES OBTAINED WITH SYNTHETIC IRONS.

## Table 13

### VARIATIONS IN FLUIDITY OF A COMMERCIAL IRON WITH VARIATIONS IN SILICON CONTENT

| Test Nos. | Carbon, Per Cent | Silicon, Per Cent | Phosphorus, Per Cent | Length of Casting at 1250 Degrees Cent.†—Cm.* | Length of Casting at 3 Per Cent Carbon—Cm.* |
|---|---|---|---|---|---|
| 17 | 3.24 | 0.037 | 1.96 | 102 | 86 |
| 23 | 3.25 | 0.037 | 1.68 | 112 | 95 |
| 4 | 3.21 | 0.075 | 1.74 | 120 | 105 |
| 10 | 3.44 | 0.150 | 1.78 | 148 | 117 |
| 5 | 3.42 | 0.110 | 1.99 | 137 | 107 |
| 24 | 3.70 | 0.170 | 1.92 | 166 | 117 |
| 3 | 3.50 | 0.310 | 1.87 | 168 | 133 |
| 25 | 3.68 | 0.340 | 1.92 | 160 | 112 |
| 13 | 3.26 | 0.470 | 1.63 | 118 | 100 |
| 26 | 3.60 | 0.490 | 1.74 | 139 | 197 |
| 35 | 3.26 | 0.505 | 1.87 | 95 | 78 |
| 8 | 3.56 | 0.540 | 1.92 | 141 | 102 |
| 7 | 3.54 | 0.600 | 1.77 | 135 | 97 |
| 36 | 3.35 | 0.680 | 1.92 | 115 | 90 |
| 31 | 3.30 | 0.700 | 1.92 | 123 | 102 |
| 45 | 3.15 | 0.710 | 1.77 | 109 | 99 |
| 42 | 3.26 | 0.800 | 1.92 | 138 | 120 |
| 37 | 3.40 | 0.920 | 1.92 | 137 | 109 |
| 9 | 3.41 | 1.010 | 1.81 | 125 | 96 |
| 44 | 3.75 | 1.130 | 1.75 | 144 | 91 |
| 32 | 3.38 | 1.650 | 1.70 | 157 | 131 |
| 43 | 3.26 | 2.450 | 1.79 | 153 | 135 |
| 41 | 3.07 | 2.930 | 1.76 | 148 | 144 |

†See footnote †, Table 1.
*See footnote *, Table 1.

pears when the iron studied has a silicon content under 0.50 per cent, regardless of the origin of this iron.

(3) With constant phosphorus, the first anomaly occurs between 0.30 and 0.50 per cent silicon.

104. In another foundry in the Liege basin, the production of a blast-furnace dealing in forge pig iron made by the Thomas process has been followed. A whole series of tests, which are found in Table 14, were obtained. In this series, the manganese content of the irons was around 1.20 per cent; sulphur, 0.12 per cent, and phosphorus was reasonably constant at 1.80 per cent. Carbon con-

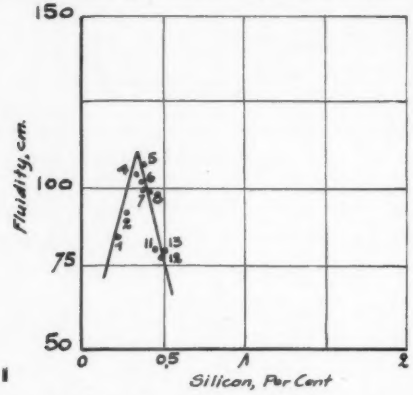


FIG. 26—CURVE SHOWING THE FLUIDITY OF AN IRON CONTAINING 3.0 PER CENT CARBON, 1.80 PER CENT PHOSPHORUS, 1.20 PER CENT MANGANESE AND 0.12 PER CENT SULPHUR WITH VARYING SILICON CONTENTS. POURING TEMPERATURE 1350 DEGREES CENT. (2462 DEGREES FAHR.)

**Table 14**

FLUIDITY OF A FORGE PIG IRON

| Test Nos. | Carbon, Per Cent | Silicon, Per Cent | Phosphorus, Per Cent | Casting Temperature—Degrees Cent.† | Length of Casting at 1350 Degrees Cent.—Cm.* | Length of Casting at 3.0 Per Cent Carbon—Cm.* |
|---|---|---|---|---|---|---|
| 1 | 3.22 | 0.20 | 1.80 | 1350 | 100 | 84 |
| 2 | 3.00 | 0.26 | 1.90 | 1350 | 92 | 92 |
| 3 | 3.60 | 0.28 | 1.80 | 1350 | 132 | 92 |
| 4 | 3.00 | 0.33 | 1.75 | 1350 | 104 | 104 |
| 5 | 3.16 | 0.37 | 1.75 | 1350 | 117 | 106 |
| 6 | 3.18 | 0.37 | 1.70 | 1350 | 115 | 103 |
| 7 | 3.20 | 0.39 | 1.65 | 1350 | 115 | 101 |
| 8 | 3.14 | 0.40 | 1.75 | 1350 | 111 | 101 |
| 9 | 3.30 | 0.40 | 1.80 | 1350 | 120 | 100 |
| 10 | 3.15 | 0.40 | 1.85 | 1350 | 111 | 101 |
| 11 | 3.16 | 0.46 | 1.70 | 1350 | 90 | 80 |
| 12 | 3.40 | 0.48 | 1.80 | 1350 | 117 | 79 |
| 13 | 3.24 | 0.50 | 1.80 | 1350 | 97 | 80 |

†See footnote †, Table 1.
*See footnote *, Table 2.

tent varied from one test to another; we have calculated it to 3.0 per cent, using the correction factor of 7 cm. (2.76 in.) for 0.10 per cent carbon; silicon contents were between 0.20 and 0.50 per cent.

105. These tests were made, moreover, at constant temperature of 1350 degrees Cent. (2462 degrees Fahr.), the actual temperature. They have permitted a branch of the curve to be drawn which shows, between 0.20 and 0.50 per cent silicon, the variation of fluidity as a function of silicon in an iron with the following analysis: Carbon, 3.0 per cent; phosphorus, 1.8 per cent; manganese, 1.2 per cent; and sulphur, 0.12 per cent. A glimpse of Fig. 26 shows that for such an iron, an iron of the first heat this time, the first anomaly occurs between 0.30 and 0.50 per cent silicon in the presence of 1.8 per cent phosphorus.

106. It goes without saying that it is not a question of wishing to compare in an absolute way the results furnished by these two series of tests, on the one hand, and personal experiences on synthetic irons. For one thing, the conditions of test and in particular the nature and composition of the cast test pieces, were not identical. However, what is of interest is that these tests permit the establishment of the existence and constancy of the first anomaly in the presence of phosphorus.

## CONCLUSIONS

107. From this research, the following general conclusions can be drawn:

(1) The fluidity test bar is a device capable of rendering service to foundrymen for the control of their product, because of its simplicity and convenience, and to the research worker, because of its precision and ease of application. For the latter, it can be used to help him to determine the liquidus lines in complex equilibrium diagrams, and it permits him to discover the physio-chemical changes which take place during the chilling of a liquid metal, or during solidification.

(2) For those interested in the study of irons, a general law may be formulated as follows: The eutectic mixtures are those which possess the greater fluidity and, therefore, are those which are most likely to give perfect castings. If the hypo-eutectics are considered, the only ones used practically, it is possible to say that the element regulating fluidity is carbon, next is phosphorus, and in a certain measure (under 1.00 per cent) silicon. As to man-

ganese, its influence on fluidity is of little importance. The amount and direction of its influence are essentially a function of the composition of the metal considered.

(3) The fluidity test bar has permitted the bringing up to date of a phenomenon whose theoretical explanation has not yet been reached. With regard to the anomalies of silicon, the one remains fixed regardless of the concentration of other elements or the nature of the iron; the other, on the contrary, shifts with the variations of phosphorus and manganese, appearing or disappearing according to the silicon content of the base iron. An explanation of these phenomena may lie in the question of modifications of physio-chemical type, accompanying the cooling or the solidification of the metal. The fluidity test bar has permitted observation of the fact but it can not tell the reason. This should be investigated, studying by improved physical means the constitution of the liquid metal.

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# Foundry Maintenance

By Jas. Thomson*, East Chicago, Ind.

**Abstract**

*The author defines plant maintenance as "sustaining the plant and its equipment in good operating condition". He cites as the main functions of the maintenance department making emergency repairs, inspection, and keeping records. A typical organization for such a department in a large foundry is given, with a plant engineer at the head; in a smaller foundry, a master mechanic would have charge of such work. The author suggests decreasing breakdowns and necessary emergency repairs by redesigning or improving the machines. Periodic inspection and careful inspectors' records form the basis for constructive repair work, and also frequently prevent breakdowns. Records are a very important part of maintenance work, and among the most needed are maps and location drawings, detail drawings of repair parts made by the department, manufacturers' repair part file, and equipment records. Standardization of material used is suggested, even though the standard applies only to the one foundry, because it permits widest interchangeability of equipment, lower inventory of spare parts, and least idle time of machines. Equipment should be selected with two points in mind; its application to the job, and its maintenance cost.*

1. The subject of plant maintenance has grown in importance in industry during the past quarter century in proportion to the extent to which plants have become mechanized and electrified. In many industries, the maintenance of the plant is a rather involved problem and is indeed one of the major items of expense. In view of these facts, proper study of the problem should be made so that the maintenance work may be kept at the proper standard and the costs be kept in their proper relation.

2. This subject is one on which volumes might be written

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Note: This paper was presented at a session on Materials Handling at the 1934 Convention of A.F.A.

but the limited space allotted to this paper will only permit the writer to give the main points without too many details. So far as the writer knows, there are no textbooks on the subject. The bibliography comprises principally occasional magazine articles on various phases of the subject, chapters in books relating to particular types of equipment, references in hand books, and information in instruction books issued by equipment manufacturers. To this must be added the more important mass of information and experience in the minds and data files of the men who have spent their lives solving maintenance problems.

3. This paper is principally a presentation of some of the fundamental principles of the organization and operation of maintenance departments as applied to foundries. It is written with the hope that it may be of value to the executives of the foundry industry.

## EXPLAINS PURPOSE OF PLANT MAINTENANCE

4. The purpose of plant maintenance is the sustaining of the plant and its equipment in good operating condition, or, as Frederick Waldron has so well expressed it, "The purpose of plant maintenance is to anticipate and prevent, to the greatest possible extent, interruptions in operation and loss of output due to bad order or broken down machinery and equipment in a manufacturing concern".

5. The main functions of the maintenance department may be stated as, (1) preventive, and (2) corrective, and may be classified somewhat as follows:

(1) Making emergency repairs.

(2) Inspection of equipment at such regular intervals as will enable them to detect wear, misalignment, etc.

(3) Following up this inspection with the necessary repairs or changes.

(4) Keeping adequate record of inspection and repairs with some sort of a tickler system to call attention to the proper time for inspection.

(5) Suggesting to the engineering department the need for changes due to excessive repairs to equipment and improvements found advisable and assisting in their development.

(6) Operating such service departments as may be assigned to the maintenance department.

6. The policy of the company will determine the size and limitations of the functions of the maintenance department. Due to the difference in size of various foundry organizations, there naturally will be a difference in size and functions of the maintenance department. It is hardly necessary to warn foundry executives about their maintenance organizations being too large or effective. The tendency in the past has been toward the other extreme.

7. It is very important that due consideration be given to monthly costs and that they be kept within reasonable limits. However, the mere examination of the figures on a cost sheet without proper consideration of the reason behind the figures is a rather short sighted policy. The unreasonable viewing of costs may drive the production manager to cut monthly expense at the risk of future larger cost. His mental attitude toward the various items of cost may be affected by the reasonableness or unreasonableness of the executive staff.

8. The production manager who is being constantly urged to hold down costs at any price, looks for places to cut. The easiest place for a while is found in the maintenance of the plant and equipment. If he has the jurisdiction over this part of the operations he can get along for a while by cutting this expense regardless of the ultimate result. However, this is only putting off the day of reckoning and at what a price! Probably, such a short sighted policy will make it impossible to bring some of the equipment back to the first class operating condition, it would have been in, had a saner policy been in vogue. Deferred maintenance is an expensive friend to have in an organization.

## OUTLINES ORGANIZATION OF MAINTENANCE DEPARTMENT

9. Without question, the amount of money which could be spent profitably in the plants of this country to take care of deferred maintenance and necessary modernization would be a stupendous sum. The foundry industry alone could account for many millions of dollars. The suggestion is offered that proper consideration and study be given to the problems involved so that the best results may be obtained.

10. In some industrial organizations the plant engineer heads the personnel of the maintenance department as well as the engineering department which has to do with plant problems. In others, the master mechanic is head of the department so far as

operations are concerned and the plant engineer acts in an advisory capacity to the maintenance department but has charge of plant engineering and construction work.

11. In other organizations, either because they are too small or for some other reason, the position of plant engineer does not exist. The maintenance work is in the hands of a master mechanic or in many cases a very ordinary mechanic or millwright whose main concerns may be only quitting time and pay day. In the latter case, there is prone to be no thought of continuity of effort, records, improvement, etc.

12. For these and many other reasons, many of the forward looking industrial organizations have established a definite plant engineering department which may or may not have jurisdiction over the personnel of the maintenance department as the particular management may determine.

## FUNCTIONS SHOWN DIAGRAMATICALLY

13. Whatever the type of organization is decided upon, it is advisable that the functions of the department be clearly defined. An organization chart is an excellent way to make the functions clear to every one concerned. Such a chart for the maintenance department in a very large foundry organization would follow the plan as shown by the upper diagram of Fig. 1. This is one set-up for an organization which has been used in several instances. A number of variations can be made to suit the ideas of the management. In a smaller organization which does not have an engineer the chart might be set up as shown by the lower diagram of Fig. 1.

14. In the chart of the larger organization, the head of the department is the plant engineer. This organization scheme refers to the cases where there is only one plant. In the case of a company having several plants, there may be a chief engineer with a plant engineer and his organization at each plant and each plant engineer reporting to the chief engineer. In the latter case, the major engineering problems and such matters as equipment selection, standardization, testing, etc. are usually handled from the chief engineer's office and the local plant work by the plant engineer's department. This is just an enlargement or development of the general scheme.

15. Inasmuch as the large majority of foundries are single

plant organizations, we will confine our explanations principally to the single plant maintenance department.

*Plant Engineer*

16. The plant engineer should be a man of experience in plant work with a good knowledge of equipment and construction work and of the work of the various kinds of craftsmen who report to him. He should be resourceful and have the type of personality which will enable him to deal with a great variety of men and their ideas. He should be able to cooperate with the other departments in the plant keeping in mind at all times the best interests of his company.

17. The duties usually assigned to the plant engineer are: plant layout, selection, design and installation of equipment, standardization, power, study of maintenance problems, construction work and tests. In some organizations, he also handles such work as estimating and calling on customers for the sales department when engineering features are involved, assisting the development of ideas for the production department, making special investigations, assisting the accounting and purchasing departments with reference to equipment matters and various other duties.

18. In the foundry industry as a whole, comparatively few companies have plant engineering departments, but those companies which have tried out the idea, have been satisfied to make the plant engineer an integral part of the organization. Others

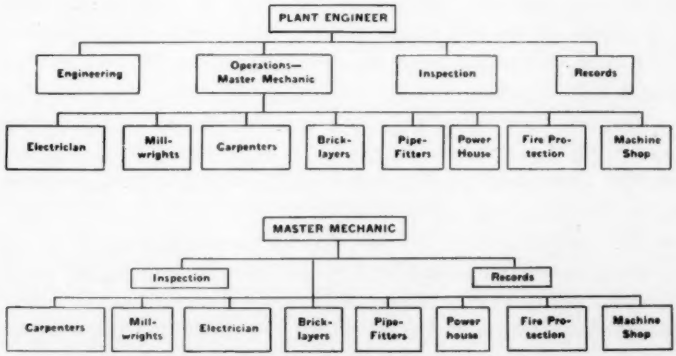


FIG. 1—ABOVE—MAINTENANCE DEPARTMENT ORGANIZATION CHART FOR LARGE FOUNDRY. BELOW—SAME FOR SMALLER ORGANIZATION.

have availed themselves of the services of consulting engineers on some of their major engineering problems.

19. In this connection, it might be well to warn that if a consultant is called in, he should be a foundry engineer and not a general consulting engineer. There are cases which might be cited where the general consulting engineer, who had no intimate knowledge of foundry problems, left a sorry mess.

20. If a consultant is called in, he should be used to assist the plant engineer in the major problems. From the very nature of things, he cannot supplant the "whole time" engineer who has his fingers on the details of the job at all times. In some cases, both are needed. The suggestion has been made that two foundries with plants in close proximity might employ a plant engineer together. He would give half of his time to each.

*Master Mechanic*

21. In plants that cannot afford an engineer, there should be a high class, experienced foundry master mechanic whose judgment should be respected and whose suggestions should be given fair and careful consideration. Executives should realize that his main object in life is to keep the plant going and that his recommendations are based on his experience and are made for the best interests of the company. He is much closer to the maintenance problem than the executives and no doubt sees many things which they fail to notice.

22. The master mechanic should have a good knowledge of the various crafts he has to deal with and be a good executive. In addition, he should possess that enviable kind of a disposition which enables him to handle the complex and troublesome job and still be able to smile.

23. Fig. 1 suggests four principal sub-divisions of the plant engineering department: Engineering, operations, inspection and records. These might be extended but we will take them as shown and discuss the duties of each briefly.

24. *Engineering:* To this division is assigned such matters as design, selection, changes and improvement of equipment, buildings, etc., plant layout, testing of materials and equipment, standardization and all plant engineering work. If the organization is large enough this division will be under the direction of a chief draftsman.

25. *Operations:* The work of the operating division is generally under the direct supervision of a master mechanic and comprises such operations as power, electricity, millwrighting, bricklaying, carpentry, pipe fitting and in some places, track work, machine shop and fire protection. Unless other provision is made, the master mechanic will have the duty of carrying out the plans prepared by the engineering division and the work indicated by the inspection division.

26. *Inspection:* The inspection division makes systematic inspection of buildings, equipment and machinery at such periods as experience indicates. They also make emergency inspections in case of breakdowns. Reports of needed repairs are made to the operating division and suggestions for improvements to the engineering division.

27. *Records:* This division takes care of records, orders, timekeeping, budgeting, filing, etc.

28. This outline of duties applies to the larger organization previously indicated. A comparison of the two charts will indicate the changes necessary to apply them to the smaller organization.

## DESCRIBES DUTIES OF VARIOUS SECTIONS

29. Having this picture of a well organized maintenance department, some of the matters which confront the department will be discussed and some suggestions offered which may be of value.

### *Emergency Repairs*

30. Emergency repairs must be taken care of as a matter of course. Break downs will occur in spite of everything that may be done to prevent them and no very satisfactory rules can be made for taking care of emergency repairs caused by these breakdowns. Each must be handled according to the best judgment of the head of the department who should take into consideration the cause of the breakdown, the kind of repair necessary and the possibility of preventing its recurrence.

31. One measure of the efficiency of the maintenance department is the freedom from emergency repairs. Frederick W. Taylor remarked that if a machine breaks down two or three times at the same point, it is nobody's fault, but if it breaks down four or five times at the same point, it is the fault of the head of the maintenance department. Very likely the only way to prevent

the recurring of these breakdowns is to redesign, strengthen or improve the part or machine. This may call for a study of the design and material of the part or machine, or its suitability for the service, by the engineers of the department.

32. As an example, the author remembers an experience with crane motors in the steel foundry. As purchased, these motors had bronze bearings. In this service, he was able to get about four months' service from a set of bearings. He tried factory bearings and home made ones of various kinds but with little improvement. It was not only the cost of replacement of the bearings and loss of use of the crane during the changing of motors but other costs from electrical troubles, excessive wear of gears, brakes and shafts that worried us. He endeavored to have the motor company supply him ball bearings for these motors but was advised that ball bearings had no place in crane motors. He was told that they would not stand up. This did not satisfy him, so he designed a set of bearings for one of these motors and put it in one of the worst places. After 20 months service, he had the motor taken down for inspection, found it in good condition and put it back into service.

33. The first tryout gave him five times the life he had been getting from bearings on these motors and encouraged him to change other motors in a like manner. He has since equipped many motors with ball and roller bearings and the maintenance cost of bearings, etc., is now a minor matter. New motors purchased in later years all were equipped with ball or roller bearings.

34. In a closely knit and properly functioning maintenance department, a careful study of emergency repairs and their causes will point the way toward improvements which will reduce them to the minimum.

*Inspection*

35. Another function of the well organized maintenance department is inspection of equipment and machinery. To be most effective, this inspection must be well planned and conducted at proper times.

36. In a large plant, there will be several inspectors, each with specific duties which are scheduled for him each day. His instructions are given in writing and will probably consist of the name of machine or equipment to be inspected, details of inspection work, kind of repair work or adjustment he is to make and nature of report he is to return. There are numerous forms for work

orders and report sheets for use of inspectors. One, which has found favor in many places, is a sort of combination tickler card, order and report card.

37. In some organizations which have established very complete inspection systems, the inspector's instructions include very definite questions which he has to answer by "yes" or "no" or definite measurements which he must report, thus preventing him from forgetting any part of the prescribed inspection. Spaces are provided for the proper answers. He also reports any condition he notices which is not covered by specific instructions.

38. These inspectors' reports are made the basis for constructive repair work. The report usually is reviewed by the head of the department or some one designated for the purpose and provides the information for real planned or scheduled maintenance work. Breakdowns frequently can be prevented since the condition of the equipment is known and repairs taken care of before the breakdown occurs.

## ARRANGE SCHEDULE OF INSPECTIONS

39. A schedule of inspections usually is arranged at first from someone's judgment and then changed as experience indicates. A tickler card system, by dates, is set up and the card for a particular job or machine put in its proper date. This prevents the inspection being forgotten.

40. This may be considered a rather cumbersome system, but it pays good dividends. An organization may think it is too small to follow this system. However, no matter how small the organization, some inspection schedule can be followed. No doubt if executives indicate to the maintenance foreman the value of a periodic inspection of equipment and sell him on the idea that they believe in it and will permit the expense, he will be anxious to follow out their instructions. Perhaps he only needs the encouragement of the suggestion to start the plan. At first, it may take more work and effort on his part, but as time passes and emergency repairs become less frequent, his trouble and the expense to the company will lessen materially. Undoubtedly, he will be in a much better position to schedule his repair and improvement work.

41. To much stress cannot be placed on the value of this inspection work. It provides the basis for the preparation of spare parts and the extent to which they should be carried. It is prob-

ably true that an adequate inspection system may permit a lower inventory of spares than if the decision as to what is to be carried is left only to guess. The periodic inspection will indicate just what to have on hand and will give a good indication of when it should be gotten ready. A study of the reports will also indicate to the engineers what is wrong with the equipment and give them a basis on which to suggest and design improvements.

*Records*

42. An adequate record system is an essential part of the well managed maintenance department. The size of the department and the functions assigned to it, will indicate the nature of the records to be kept by each division. If the department is of sufficient size, a clerical force will be needed to keep up the records aside from those kept by the engineering division. In the small plant the foreman will probably keep his own records.

43. The following indicates the kind of records to be kept:

(1) Drawings of buildings
(2) Maps of property
(3) Maps of steam, gas, water and sewerage piping and electrical wiring
(4) Track maps
(5) Foreign prints and data regarding machinery
(6) Detail drawings of repair parts made by the department
(7) Department layouts of equipment location
(8) Manufacturers' repair part lists and specifications
(9) Record cards of all equipment
(10) Catalog file
(11) Inspection record
(12) Order file
(13) Standardization information
(14) Power reports
(15) Photographs of equipment and plant
(16) Engineering data

## RECORDS ARE VALUABLE

44. The whole time allotted to this paper might be spent discussing the subject of maintenance records and their value. Permit me to mention only a few points.

*Drawings*

45. Much time of executives, engineers and maintenance men can be saved by having adequate maps and location drawings. In considering new problems of layout, location of equipment, buildings, tracks, etc., they are almost indispensable.

*Repair Parts File*

46. Detail drawings of parts for repairs or replacements such as bearings, shafting, gears, keys, brake wheels, etc., which are made in the company's own shop, are of the utmost importance. The information has to be procured to make the repair in the first place, so why not put it in a permanent form in a detail drawing so that it is there for use the next time the repair is necessary and also so that the part may be made up before it is actually needed, as the inspection reports will indicate? Changes should not be made in parts unless a detail record drawing is made. Equipment designed in the plant will, of course, have complete detail drawings and specifications. A manufacturer's repair part file, which should be in duplicate, one copy in the engineering department and one in the master mechanic's office, is very useful when ordering parts from the manufacturer.

*Equipment Records*

47. An equipment record should be kept which has the equipment properly classified and indexed. This should show such information as description of equipment, location, date of installation, serial number, name of manufacturer, order number, cost, etc. This record, if properly maintained, will serve as a perpetual inventory of equipment and its location. It will be valuable not only to the maintenance department but to the accounting and engineering departments as well.

*Order System*

48. The order system in use will depend greatly on the desires of the accounting department of the company.

## STANDARDIZATION OF EQUIPMENT PROFITABLE

49. Standardization cannot be successfully carried out without proper records. Time will not permit a full discussion of this subject but mention can be made of a few items, viz: painting standards, piping identification colors, flank design standards, crane detail standards, gear and bearing records, electrical equip-

ment, stoppers and nozzles for ladles, specifications, standard fits and tolerances, safety codes, and engineering standards.

50. Foundry maintenance and engineering departments should use recognized standards as far as possible and their record system should contain copies of such standards; for example—standard screw threads, bolts, screws, keys, engineering symbols and nomenclature, machine part standards, etc. Materials should be standardized to the fewest practical number of kinds, sizes, grades, etc.

52. It is extremely difficult to determine how far to go with the standardization of machinery and equipment. However, serious consideration should be given to such standardization as will permit the widest interchangeability of parts consistent with the greatest usefulness of the equipment and improvement in its design.

### CITES EXAMPLE OF STANDARDIZATION

53. In cases where no general standard exists, it is often desirable to establish one which, while it applies to only one foundry, will save money by lowering inventory of spare parts and stores, standardizing methods of repair work, reducing the idle time of machines and preventing duplication of effort. For example, a foundry has ten cranes of various sizes, each with main and auxiliary hoist. This represents electrical equipment as follows: 40 motors, 40 controls, 20 to 30 solenoid brakes and 20 limit switches. These cranes may have been built by 4 or 5 different manufacturers and there probably will be a large variation in sizes and types of motors, controls, brakes, couplings, truck wheels, etc. Why not standardize in this plant so that there are as few sizes and makes of motors, etc. on the cranes as possible, and thus reduce to the minimum the spare parts necessary for efficient upkeep of these cranes. In other words, insist on the manufacturer considering the customer's side of the question.

54. In our plant at East Chicago, we have standardized sizes of crane motors, controls, brakes, couplings, gears, bearings, truck wheels, etc. so that today with 21 cranes we have less maintenance troubles and probably no more spares than when we had only nine. This was not accomplished in a year but by establishing a standardization policy years ago and sticking to it. And the job is by no means complete.

55. The same policy is being followed in many other ways. For instance, we have gone a long way toward the standardization

of flasks. Ladle stoppers and nozzles are standardized; painting standards have been adopted; a color scheme for piping identification based on the A.S.M.E. report has been set up; some sizes of grinding wheels have been made standard; and certain kinds of materials have been tentatively standardized.

56. No matter how small or how large the plant, serious consideration should be given to standardization *within practical limits.* After establishing the policy, insist that the maintenance department stick to it within reason. The results obtained will be told in terms of lower maintenance costs, higher efficiency, and increased production.

57. While on this subject of standardization, the author suggests that the A.F.A. could be of considerable assistance by establishing some sort of a standardization committee to consider and pass along the data after it has been decided upon. The author has particular reference to an engineering standards committee.

58. In comprehensive standardization work, it is often necessary to carry on tests of various kinds. Manufacturers make certain claims for their material or equipment and before adopting any standard it is necessary to determine what make is best adapted to the plant or product in question. Several methods are available for securing the desired information. In our opinion, the best is to allow the plant engineering department to conduct such tests. If the conduct of such tests is turned over to the plant engineering department, with the strict order that there be no interference, that department can become a real fact finding agency and can render unbiased reports. That method is used in several organizations and is adhered to strictly. All testing of materials and equipment should be carried out by the plant engineering department.

### FUNCTIONS OF OPERATING DIVISION DISCUSSED

59. In the larger type of organization, the operating division handles the repairs and changes indicated by the inspection reports, the work planned by the engineering department, the emergency repair work and service work such as power house, millwright work, pipe work, carpentry, brick work, electrical repair and construction, crane service, track work, fire protection, maintenance machine shop, etc.

60. In the smaller organization, some of these functions and that of inspection are combined and a few men have various duties to perform. For instance, there may be only one electrician. He

must be electrical inspector, armature winder, trouble shooter and installation man. With proper cooperation of the men in even a small organization and with proper planning and encouragement from the executives, a good job of maintaining the plant can be done.

### DISCUSSES EQUIPMENT MAINTENANCE

61. In a broad sense, the subjects of equipment and maintenance are so closely interrelated that one should not be thought of without the other. Immediately after the installation of the plant or a piece of equipment, maintenance costs start. They may even occur before the plant or equipment is put into operation. Deterioration, depreciation and obsolescence start immediately. Hence, the advisability of making provision for proper maintenance from the start.

62. Many foundries start with good equipment and buildings but in the effort to show a low operating cost, proper maintenance is completely ignored. In a few years, such condition becomes so acute that tremendously high maintenance costs have to be met to keep operating. Then, the plant must be brought back to a fairly decent operating condition but at great expense, and no doubt some of the equipment can never be placed in the condition it would have been in if proper attention had been paid to the upkeep from the start.

63. Foundry equipment should be designed and selected with two thoughts in mind: (1) its application to the job and (2) low maintenance cost. Low first cost should not be the criterion in selecting equipment for the foundry but rather the questions of whether it will do the work properly and have as low maintenance as possible with proper attention. Much of the foundry equipment produced in the past has left out the latter consideration. This may be partly our own fault for not insisting on proper design rather than buying something because someone had it for sale. Cheap equipment usually means high maintenance.

### AVAILABLE EQUIPMENT NOT ALWAYS SUITABLE

64. For many years, the manufacturers in general failed to appreciate that there is a vast difference in the different branches of our industry. They sold equipment to steel foundries, which was perhaps fairly well suited to iron foundries. To the general observer, this may have seemed all right, but to those who know, it is entirely wrong. Equipment should be designed to suit the

particular branch of the industry in which it is to be used. Speaking for the steel foundry, we are very frank in saying that even today, much of the equipment on the market is not entirely suited to our requirements. Not referring to any make, we doubt whether the entirely satisfactory steel foundry crane, sandblast, sand handling or preparing machinery, molding machine, tumbling barrel, to mention only a few, has yet been produced. We will be frank in admitting that some of the equipment is better than it used to be, mainly as a result of the insistence of our production managers and engineers for improvement, but there is still much to be desired. Questions of lubrication, dust proofing, materials, etc. have in many cases not been properly answered.

## EQUIPMENT IS CHANGED

65. We, in the steel foundry, are considering what is best for our own companies while the manufacturers seem to be considering mainly the economical production and sale of their product. We have been told by several manufacturers' representatives that the kind of equipment we want built could not be sold. That is a foolish statement. If the equipment is built better, they are entitled to a better price. The saving to us will be in reduced maintenance cost. Why should we buy a machine built to their ideas alone and soon after it is installed have to begin improving it to fit the job better or reduce its maintenance cost? The history of equipment for steel foundries is replete with such cases because nothing better was available. Why have so many steel foundries had to build part of their own equipment? Either because nothing suitable was available or such as was presented would not "stand the gaff".

66. Some manufacturers of equipment fail to issue adequate operating and maintenance information about their product, leaving it to the user to find out the information from experience. They blame the operator or maintenance man for something which is done contrary to their ideas of best practice, while the real blame should be placed on their own shoulders for not providing clear and adequate information. Well illustrated and marked repair part lists should be supplied with maintenance information so that there need be no mistake when ordering replacements. These bulletins should preferably be 8½ in. × 11 in. to fit the letter size file.

67. These observations are not intended in any way as a tirade on manufacturers of foundry equipment but rather as a

statement of facts, and surely we should all be willing to face facts. Manufacturers should wake up to the needs of the industry and the opportunities facing them. The conditions and mistakes of the past need not continue. With the development of a new attitude toward maintenance problems, there is now a common ground on which the manufacturer and the foundry engineer can stand, to plan better equipment than we have yet seen. From that planning will evolve that day to which all foundry executives have been looking forward, when maintenance costs will be much lower than at present.

### DISCUSSES USED EQUIPMENT

68. Before leaving the subject of equipment we wish to mention briefly the much discussed question of used or second-hand equipment. In some organizations, when it is decided to add another piece of equipment the first question usually is "Can we buy a second-hand one?", rather than "What is the best thing to do under the circumstances?". We are not saying that new equipment should always be bought, but that the question should be answered by taking into account all the factors such as, the job, money available, price, condition of the machine, can we afford to rebuild it if necessary, its obsolescence, the overhead chargeable to it, etc. Think the problem through before buying. Perhaps the new machine will be cheaper in the end considering everything, perhaps not, but be very sure *all* the factors are considered.

### CONCLUSION

69. Probably all foundry companies had to interrupt their maintenance plans during the depression. Many of these plans or others in their place will be reestablished as we climb out of the depression. It is to be hoped that those companies which have never had any comprehensive plan of maintenance will take cognizance of the trend of the times and organize some adequate maintenance personnel suited to their own particular case, so that their maintenance problems will be given the consideration they deserve.

70. An endeavor to be of some assistance to those who may be thinking along the line of planned maintenance has prompted this paper. While it has been of a rather general character, it is hoped that the suggestions presented will be useful in directing thoughts in the proper channel.

## DISCUSSION

J. A. SWEENEY[1]: Does Mr. Thomson recommend that crane operators come under the maintenance force in a production shop, and if so, why?

MR. THOMSON: In our operations, we do. We have tried both methods, one being that they come under the operating superintendent and other that they come under the master mechanic. We find that the wear and tear on the machinery has been materially reduced when these men are responsible to the master mechanic. There is no trouble at all in the master mechanic co-operating with the foreman on the floor, because one of the instructions the crane operators get is that they must take their operating instructions from the foreman on the floor.

But, the crane operator is responsible to the maintenance department for the care, or the use, rather, of that piece of machinery. We have had a considerable reduction in maintenance cost on the cranes since we have used this plan. Cranes in a steel foundry are one of the major items of maintenance expense, and anything you can do to keep them running 24 hours a day and not endanger the future proper maintenance of the crane, is valuable to your company.

J. A. SWEENEY: I understood the author to say that there are organization set-ups in the country where the master mechanic is not subject to the plant engineer. Personally from my experience, it is a poor arrangement and I would like to confirm his opinion.

MR. THOMSON: The best arrangement is to have the master mechanic report to the plant engineer for the reason that it keeps the two parts of an organization which are doing the same thing closely knit together. The plant engineer is really the executive in charge of the maintenance department and the master mechanic is the one who, while he is reporting to the plant engineer, is actually taking care of the operating end of the work. This method perhaps might not work in some cases. You have to be somewhat guided by the qualifications of the man and his ability to do certain things.

CHAIRMAN E. W. BEACH[2]: In Mr. Thomson's plant organization diagram, the sequence of responsibility was directed from the engineer department to the plant engineer, through the master mechanic. Then, later we see coupled in the same bracket, inspection. We have tried this sequence ourselves and found it rather a vicious circle. It brings inspection responsibility back to the origination of a scheme, or the designer of a machine, and we are all loath to criticize ourselves.

In our plant, we have recently divorced the maintenance department from the engineering department and placed it directly and solely under the plant superintendent who has recourse to the engineering department. Thereby, we have placed the engineering department in a position where criticism of performance may be made with salutary effect.

J. A. SWEENEY: Just what tieup would there be between the master

[1] Florence Pipe Foundry & Machine Co., Florence, N. J.
[2] Campbell, Wyant and Cannon Foundry Co., Muskegon, Mich.

mechanic and the shop superintendent? There is a sort of crossover where your crane operators are coming under the master mechanic, and the master mechanic, in turn, comes under the engineering department. In other words, is it a question of co-operation between the master mechanic and shop superintendent?

MR. THOMSON: Yes. Right along the line of Mr. Beach's remarks, a lot depends on the plant. In some plants, it would work one way, and in some plants another way.

In our organization, the master mechanic does not come under the plant engineer. We have found out, as Mr. Beach states, that it is a better scheme because it leaves the plant engineer somewhat as a free lance to criticize and design and select equipment independently.

In another organization, the other scheme might work out; the maintenance men being under the plant engineer.

CHAIRMAN BEACH: After all, maintenance, particularly in production plants, is for the purpose of avoiding the costly interruptions of straight-line production. We feel that better service is rendered in the plant if the plant superintendent has direct connection and control of his immediate and necessary changes, alterations, and repairs, rather than having to go to the engineering department and then go triangularly over to the maintenance department and then have the shop come back to the superintendent to know exactly what was required, if there is any doubt in the master mechanic's mind.

Of course, either point in this triangle has recourse to the engineering department for help and suggestions but the direct contact of plant manager and master mechanic has, in our case, been most satisfying.

MR. THOMSON: Mr. Beach, have you any restrictions on the maintenance department making changes in the plant without the engineering department being in on it?

CHAIRMAN BEACH: We have. No changes in the location of machinery, layout of units, or even cutting of holes in the roof or sidewalls of a building may be undertaken without the sanction of the engineering department, unless it is an emergency measure.

MR. THOMSON: How about changes in parts of a machine? For instance, some fellow in the maintenance department gets a notion that he wants to change the speed of a machine and put in some other gears. Are they permitted to do that?

CHAIRMAN BEACH: They are not supposed to. I presume that we catch 50 per cent of such changes. If there is time, they ask us; if not, they make the change and tell us later—sometimes.

MR. THOMSON: We make an effort to keep a correct record of all the parts that we have drawings for and if some maintenance man, of his own volition, changes something without reporting it, then the next time you want to use that part, or to replace it, there is no correct record of it. In this connection, manufacturers' parts lists are important factors.

CHAIRMAN BEACH: In regard to what Mr. Thomson has said about manufacturers' parts lists, I do not feel that in having sold a piece of equipment, the manufacturer quite lives up to his responsibility in that

when parts lists are changed if he does not take the trouble to go into the field and say, "Gentlemen, here is a new list which applies to our equipment; please destroy your old ones." Some of them do.

During the past year, I have tried to rehabilitate our catalog files and it has been a tremendous task. A lot of the companies which are represented in our files are out of business. Machines of such manufacturers, are orphans so far as repair parts are concerned. To offset this problem, we now insist that the manufacturers send us, within the limits of reasonable business judgment, blueprints with details with all new equipment purchased. I do not see why they should not. We accept their judgment in design, but we are entitled to know what the details of the machine are in case we have to make emergency repairs. We have a catalog file that embraces 7000 firms. It is a very miscellaneous collection of pamphlets and catalogs. We file them very carefully and we cross-index them. Parts lists are important and it would be well for us all to go over our various units and see that we are up-to-date in this particular. It not only helps us but manufacturers are helped in supplying their products if properly described in orders.

A. F. ANJESKEY[3]: We are manufacturers of overhead materials handling equipment and we have our share of troubles in furnishing proper information on repair parts to users of our equipment, particularly on electric hoists. When we ship an electric hoist to a purchaser, a repair parts list is tied to the hoist, with proper notation on the envelope that the list is to be saved for future reference when repair parts are required.

When delays in ordering repair parts arise, it is due to the fact that this repair parts list was destroyed when the hoist was unpacked. We do not find this out until the user wishes to buy these parts, and, as a rule, he is in a hurry for these and delays occur because it is necessary for us to send him a new repair parts list or have one of our representatives call on the user and determine what part is necessary.

We have tried to decrease delays by sending large users of our equipment a separate list for the stores department and also one for the engineering department, but we have found that this has also caused delays, as the man in charge of the maintenance department would sometimes incorrectly order the part and the stores department, in making up the requisition, instead of checking its own records, assumes what part is needed without fully checking with the maintenance department.

When the part is received by the maintenance department and found to be incorrect, we, as the manufacturer, are criticized, but, upon investigation, the blame can be traced either to the stores department or maintenance department or both, because they apparently have not cooperated in preparing their requisition and order.

How can this be corrected: I agree with Mr. Thomson that a lot of manufacturers do not supply their customers with enough information on repairs, but I believe our company does as good a job as it can. These delays could be eliminated when discussed thoroughly.

CHAIRMAN BEACH: In our organization, we have a definite rule that

[3] Cleveland Electric Tramrail Div., Cleveland Crane and Engineering Co., Wickliffe, Ohio.

our numbered catalogs must not go outside the engineering office, and equipment blueprints must not be removed from there. We even go to the trouble of duplicating prints that we cannot get elsewhere to try to preserve our catalog and blueprint file intact, but in spite of this rule they disappear.

It is said that the parts lists are tied in or packed in the crate. If that is done, they rarely get to the maintenance department office. If they are sent by mail, they stand a better chance of reaching the right desk.

A. F. ANJESKEY: As mentioned before, one large user of equipment received three sets of repair parts lists, one for the engineering department, one for the stores department and one for the maintenance department, and with reasonable cooperation between the three departments, the difficulties in obtaining repair parts can be eliminated. We, and other manufacturers, can make prompt shipment of repair parts when we know what is actually required.

I would also like to make a remark in defense of the manufacturers of equipment sold to the foundry industry. Since the depression many foundry executives have felt that they could buy equipment and reduce their costs, if such equipment could be bought at a price. Many equipment manufacturers are requested to submit a quotation on what they believe is proper for the application; the prospect states that he cannot pay the price asked, with the result that the "auction sale" starts, substitutions are made in equipment, and the order is usually placed with the lowest bidder, with the result that the purchaser does not always obtain equipment that is heavy enough to stand up under service with a minimum of maintenance. If more consideration was given to engineering details than price, greater satisfaction would result for both the manufacturer and the purchaser.

During these trying years, a common remark is "If we can only get by for three years" or "If this equipment will stand up for two years, at the end of that time the depression will be over and we will be able to buy better equipment." However, the purchaser overlooks the fact that he is going to use it now just as hard as he will in prosperous times, with the result that lighter or cheaper equipment does not stand up and the manufacturer is criticized.

Equipment for foundry service must not only have the ability to stand up under occasional overloads, but it is subject to wear due to heat and dust conditions in the foundry, and provision can be made in the equipment to stand up under these conditions, if the purchaser is willing to pay the price.

CHAIRMAN BEACH: I think Mr. Thomson covered this phase of equipment purchase in that part of his paper where he said that foundrymen should look well to the necessity and the requirement for which they are making their equipment. The purchaser should fully understand his own needs, and if he does not, he should consult with someone who does; then buy honestly and directly for the result which he wishes to obtain. I believe more and more that there is a tendency to

get along without quite as much to buy advisedly for the direct need, in stability and in design.

MR. THOMSON: In the paper, I mention the fact that equipment bought at a low price is not always the cheapest in the end. Our engineering department tries to be neutral between the operating end and the purchasing department and we try to pick out equipment which, in our estimation, will do the job best and at the same time have the lowest maintenance cost. It is soon forgotten what you paid for the piece of equipment, but after it is in the plant you constantly face the cost of operating and maintaining it.

Referring to another point brought up, it is wrong to put a repair part list into the box with a piece of equipment, because, as Mr. Beach says, it disappears. We try to have manufacturers send two copies to the engineering department; the engineering department puts one in their files and sends the other to the master mechanic's office with a letter saying that "Here is so-and-so," and the date noted.

We have pretty good master mechanics but every now and then they will come and say, "You failed to send me a repair part list for that hoist." We say, "Is that so?" All right, we go to the file and there is our letter stating that on a certain date he was sent the list and we tell him to go out and find it. He has probably taken it out of his file and forgotten where he put it. However, we have it in the files in the engineering department. He cannot take that one out, but he comes to our office and makes out his requisition for whatever he needs.

Nobody makes out a requisition for repair parts except the master mechanic. That centers all the ordering in his hands. The storekeeper is not interested in what the number of a part is, as long as it is on the master mechanic's requisition that he wants "WXYZ So-and-So." We have little trouble, if the manufacturer gives us specific information about how to operate and maintain a piece of equipment.

What a terrible job it is to ask a manufacturer for a blueprint or the detail of a machine! You would think that you were taking their life away. Yet, if you sell that piece of equipment to the United States Steel Corporation, you have to give them complete detailed drawings of it, or they will not buy your equipment. Why can't a foundry get the same consideration?

It is high time the foundry industry should take the same attitude when buying a piece of equipment. We want the drawings, not because we want to build a duplicate, but because it makes it a lot easier to maintain the equipment.

CHAIRMAN BEACH: The procedure as outlined by Mr. Thomson is one that we are now pursuing. On our purchase order is written, "Kindly send two full sets of parts lists, operating schedule, or directions, with the invoice." The manufacturer rarely fails to comply with the request. Our orders for especially designed machinery or equipment bear this statement, "Certified set of blueprints must accompany the invoice," and it is working to our benefit.

R. J. HEISSERMAN[4]: There has been reference made to equipment

not being built properly for foundries.

The company I represent recognized years ago, after considerable experience with conveying materials in foundries, that, to successfully handle abrasive material, required equipment built special for the severe service. In the years that followed, it has been a matter of experience and education, for both the foundryman and the equipment manufacturer, that has made possible the present type of low maintenance equipment. Anti-friction bearings and enclosed speed reducers are rapidly replacing babbitted bearings and open gears. Many other such improvements are being offered to the foundry industry that soon return their extra cost in reduced maintenance and operating costs.

MR. THOMSON: In defense of the manufacturers, I would like to say that some of them have really worked with us. I have been in foundry engineering about as long as anybody in the country, about 28 years, and I am beginning to feel old at it. In the beginning, you could not buy anything that was suited to a foundry. There was no question about that, but some companies have cooperated with us and have taken our suggestions and we have taken their recommendations. I would like to warn foundrymen that when a company comes to you with something that they think is superior, give them consideration. Don't just because it costs a few nickels more than similar equipment, turn them down. They may have something that will save you a lot of money. The manufacturers, on the one hand, and the foundry executive and the engineer, on the other hand, should work closely together because the result is going to be better equipment.

[4] Link-Belt Co., Philadelphia, Pa.

# The Work of Rupture and the Mechanical Strength of Gray Cast Iron†

By J. Navarro Alcacer,* Valencia, Spain

**Abstract**

*This work, the first part of which will be found in a paper presented by the author at the Prague Congress (1933), contains a collection of formulae by means of which one may set up equations for the mechanical coefficients which today interest the producer and user of gray cast iron. By the use of the relations established by the author, the study of the material from different mechanical points of view ought to be simplified and shortened. All tests have been made with small test specimens, taken from the same piece, made from the ordinary types of cast iron. Attention is called in particular to the important role which the work of rupture plays. By means of it, one is able to connect up the mechanical coefficients.*

1. The present work is a resumé of numerous experiments carried out with the intention of offering the industry a rapid and easy control of the mechanical properties of gray cast iron. All tests were made with small test specimens in a Fremont type machine constructed in the Precision Department of the Spanish Artillery and checked in the laboratory of the Advanced Technical School of Valencia.

2. The advantages and disadvantages of test specimens cut from the casting itself will not be discussed. There already have been long discussions on this subject at various meetings and congresses.[1]

3. If small specimens of gray cast iron, regardless of class, cut from different positions in the same casting, are tested, the values obtained will be different, though not varying greatly from each other. This diversity of results is enclosed between limits (the less frequent values), which embrace one part or another of

† The Association is indebted to W. H. Spencer, American Cast Iron Pipe Co., Birmingham, Ala., for the translation of this paper.

* President, Spanish Committee on Testing Materials, Valencia, June 1934.

[1] Portevin, A., *"Report on Mechanical Tests of Cast Iron Specimens,"* International Congress for Testing Materials, Amsterdam, 1927.

Note: This paper is the Spanish Exchange Paper and was presented at a session on Cast Iron Founding at the 1934 Convention of the A.F.A. and the Fifth International Foundry Congress.

the probable numerical scale, according to the structural characteristics of the place tested. If the frequency curves are studied and the average values for the values obtained are found, it will be noted how great and decisive is the influence of the position of the test piece in the casting. This influence, since chemical analysis is the same, is due to the cooling rate of the casting.

## STUDIES SURFACE-VOLUME RELATIONS

4. In another work[2], the author has shown that cooling rate is decisive for the structure of the material and how this explains certain facts which are incomprehensible when only the wall thickness of the casting is considered. Values of $\frac{\text{surface}}{\text{volume}}$ for cylindrical rods and tubes have been compared. This quotient is proportional to the cooling rate. A tube and cylinder of different wall thicknesses (20 mm. or 0.7974 in.) and 50 mm. (1.6685 in.) diameter respectively), having the same ratio $\frac{S}{V}$, had very similar micrographic structures containing pearlite, abundant ferrite, and large graphite. The consideration of thickness alone as a criterion of analogous structures leads to fundamental errors.

5. A complicated casting will give a great diversity of cooling conditions, so it is useless to speak of one strength for the entire casting. It only remains to find the strength in a certain location, either the most dangerous or most interesting, by taking thence some test pieces, more or less numerous according to the importance of the case and the experience of the tester.

6. The test pieces being removed, finished and broken, it is necessary to measure and interpret the diagrams obtained. Shortening the calculations and finding the numerical relations between the mechanical coefficients saves much of the time employed in testing. Obtaining clear relations between the constants is equivalent to distinguishing a cast iron by means of three or four coefficients almost immediately after a test by only one method. The extent to which the average plant is inclined to scientifically control its products depends on the ease and simplicity with which the tests offered may be made. That is the object of the present work.

7. *Work of Rupture:* The first thing that was necessary in this study was to find a coefficient which, in its relation to the

[2] Navarro, J., *"Some Thoughts on the Mechanical Tests of Gray Iron,"* Conference organized by Association Technique de Fonderie, March 14, 1934.

others of interest to the engineers and in its graphical representation with other coefficients, would not give a cloud of dispersed points. These graphs do not offer more facts than statistical studies, but are better for the average manufacturer who desires to have concrete figures and not brilliant studies of probability.

8. Work of rupture of the test pieces has been used as the coefficient of relation to the various mechanical coefficients. The work of rupture, in the cases tested by us, as much in the transverse test as in those of compression and shear, is intimately bound to the respective mechanical coefficients by a simple equation of the first or second degree. That equation is independent of the structural variations of the matrix of the cast iron and of the distribution and form of the graphite, at least within the limits of our experiments which include all the ordinary types of gray cast iron.

9. The work of rupture, a product of force and deformation, offers in its integration a perfect concept of that which takes place in the material. This in reality ought to oppose, at each instant during the test, its momentary potential energy to the sliding of the atomic lattice. The work of rupture is, given by the machine, the true history of that which takes place in the material and not a concept elaborated with hypotheses as it happens with bending and on a smaller scale with the concept of hardness and the coefficient of rupture by the tensile test. The coefficient of rupture is an excellent means for characterizing gray cast iron, especially since it offers also the advantage of giving simple and exact relations with the mechanical coefficients ordinarily employed in construction technique.

10. *Relation Between Transverse Breaking Load and Its Work of Rupture. The Tangent at the Breaking Load and Its Relation to the Factors Cited.* We have already published in former works the relation found experimentally by us between the transverse breaking load and the work of rupture. With test pieces $10 \times 10 \times 58$ mm. ($0.4 \times 0.4 \times 2.28$ in.), the equation was:

$$S_f = 10.46 \sqrt{T_f} \quad (1)$$ *

11. From the study of the curve $S = C\sqrt{T}$ ($S$ = development of the curve of the diagram), and from the solution of the differential equation which results on substituting

$$dx\sqrt{1 + \left(\frac{dy}{dx}\right)^2} \text{ for ds and } \int_0^x y\,dx \text{ for } T, \text{ there is deduced,}$$

* For meaning of symbols, see Appendix I, page 671.

after some simplifications, $y = H\frac{\sqrt{1+p^2}}{p}$ and

$$S_f = 8.7\,\frac{\sqrt{1+p^2}}{p} \qquad (2)$$

in which $p$ is the tangent of the angle at the breaking load (Fig. 1).

12. It is easy, on combining (1) and (2), to arrive at

$$T_f = 0.7\left(\frac{1+p^2}{p^2}\right)^{\dagger} \qquad (3)$$

13. *The Mean Coefficient of Elasticity* $\frac{x}{y}$, *as a function of* $p$. If, in the equation

$$y = H\,\frac{\sqrt{1+p^2}}{p},$$

the value $\sqrt{1+p^2}$ is taken as 1, since $p^2$ is very small, the equations $y = \frac{H}{p}$ and $dy = -\frac{H}{p^2}dp$ result. The quotient $\frac{x}{y}$ which expresses the mean elasticity, since $x = \int p\,dy$, has the value,

$$\frac{x}{y} = \frac{\int p\,dy}{\frac{H}{p}} = \frac{p}{H}\int p\,-\frac{H}{p^2}dp =$$

$$p\int_0^p -\frac{dp}{p} = p\ log\ \frac{1}{p} \qquad (4)$$

14. The mean elasticity can be expressed also as a function of $p$. This function increases as the values of $p$ increase, within the experimental limits.

15. The graphical representation of (1), (2), (3) and (4) is given in Fig. 2. The value $\frac{x}{y}$, calculated by the equation (4), may be considered as the "elastic type." Cast irons may deviate slightly from that value (Fig. 3) as a result of one ($AA$) being a little more elastic than the other ($BB$).

16. The experimental and theoretical curves for $p$ do not coincide exactly because of the approximation admitted in the

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TRANLATOR'S NOTE: In equations 1, 2 and 3:
$S_f$ = Tranverse breaking load.
$T_f$ = Area between the transverse stress-strain curve and the x axis.
$C$ and $H$ = constants for each curve or type of cast iron.

calculation. But, within the field of our experience, one can be substituted for the other in the same way as the lines

$$\frac{x}{y}=p \log \frac{1}{p}$$

denoted in the beginning the value of the curve $p$, experimental and theoretical.

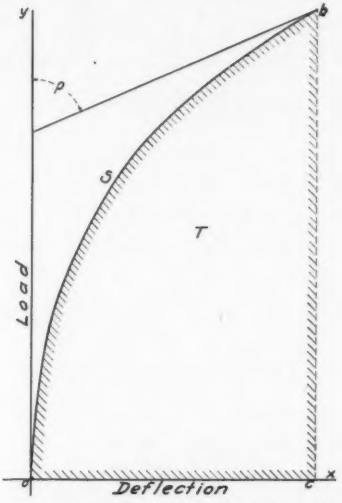


FIG. 1—TRANSVERSE STRENGTH PLOTTED AGAINST DEFLECTION.

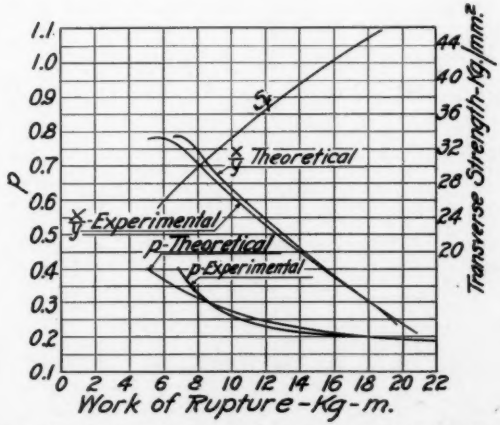


FIG. 2—GRAPHICAL REPRESENTATION OF EQUATIONS 1, 2, 3 AND 4.

17. Fig. 2 shows likewise the evolution of all the coefficients, $S_f$, $T_f$ and $p$, and corroborates quantitatively that which we already knew qualitatively, namely that gray cast iron which has lower strength is more elastic and the reverse. We have taken into account, moreover, the great importance of the work of rupture, which once known, gives immediately the "type" strength and elastic properties which scatter very little for normal cast irons.

18. *Relation Between Work Absorbed in Shear Test and Cor-*

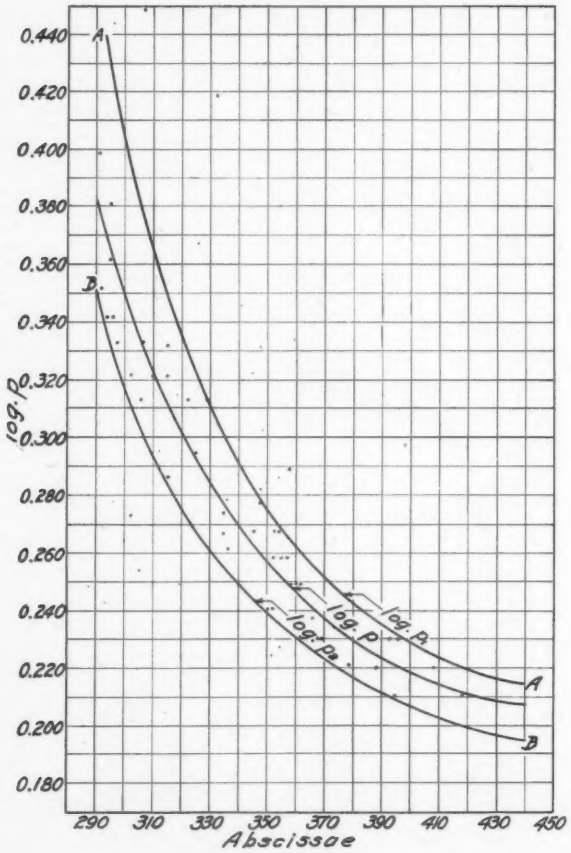


FIG. 3—IRONS CHARTED ACCORDING TO THE VALUE $\frac{x}{y}$.

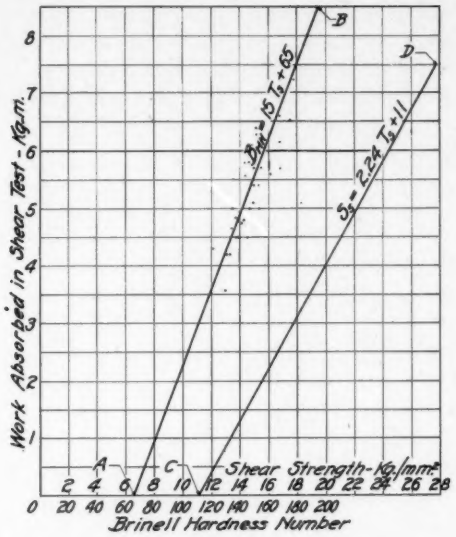


FIG. 4—GRAPHICAL REPRESENTATION OF EQUATION 5.

**Table 1**

RELATION BETWEEN WORK OF RUPTURE IN SHEAR AND BRINELL HARDNESS

| Test Bar Number | Work of Rupture in Shear—Kg. | Brinell Hardness | Test Bar Number | Work of Ruptare in Shear—Kg. | Brinell Hardness |
|---|---|---|---|---|---|
| 20-A | 6.75 | 159 | 35-C | 5.7 | 150 |
| 20-B | 6.15 | 169 | 35-D | 5.1 | 150 |
| 20-C | 7.25 | 179 | 35-E | 5.4 | 151 |
| 20-D | 6.6 | 169 | 40-A | 5.4 | 154 |
| 20-E | 6.55 | 176 | 40-B | 5.57 | 144 |
| 25-A | 4.97 | 141 | 40-C | 5.57 | 136 |
| 25-B | 5.6 | 162 | 40-D | 5.57 | 148 |
| 25-C | 5.7 | 156 | 45-A | 4.5 | 146 |
| 25-D | 5.8 | 147 | 45-B | 4.2 | 133 |
| 25-E | 5.7 | 169 | 45-C | 4.75 | 142 |
| 30-A | 5.8 | 144 | 45-D | 4.5 | 138 |
| 30-B | 5.5 | 136 | 45-E | 4.76 | 139 |
| 30-C | 4.3 | 122 | 50-A | 4.83 | 144 |
| 30-D | 6.3 | 153 | 50-B | 4.54 | 139 |
| 30-E | 6.4 | 153 | 50-C | 4.21 | 131 |
| 35-A | 5.4 | 154 | 50-D | 4.85 | 138 |
| 35-B | 6.1 | 150 | 50-E | 4.67 | 135 |

*responding Mechanical Strength.*[2] As a result of expressing the average values of some 300 tests, made with small cylindrical bars of 25 sq. mm. (0.038 sq. in.) cross section, extracted from castings of variable thickness, we have set up the equation which locates these points (Fig. 4).

$$(5) \quad S_s = 2.24\ T_s + 11$$

19. *Relation Between Work Absorbed in Shear Test and Brinell Hardness.* In one of our former papers[3], we have shown that the coefficients of shear and Brinell hardness, put as a function of structural change (thickness of round pieces), follow curves parallel to the paths of the lines which describe this process (Fig. 5). Only in the field of thinner sections—fine grain and pearlitic matrix—is there observed a separation of the lines which describe the evolution of the values mentioned.

20. This suggested to us the possibility of a relation between hardness and the work of shearing. To that end, we drew the average line *A B* (Fig. 4) of the points taken from the values in Table 2. Its equation is

$$(6) \quad B_{hn} = 15T_s + 65$$

We have placed in the same Fig. 4 the relation $S_s$—$T_s$; which is similar to (6) but diverges slightly. This confirms the almost parallelism to which we have alluded in speaking of Fig. 5. Here, as there, one notes the divergence in the field of greater coefficients.

## TRANSVERSE AND SHEAR RELATION

21. *Relation Between Work of Rupture in Tranverse Test and in Shear Test.* $\frac{T_f}{T_s} = \mu$. On dividing the work of rupture in the transverse test by that in the shear test we have obtained, with test bars of the dimensions previously stated, values which vary between 1.75 and 3.0. The most frequent values were between 2.0 and 2.5.

22. In similar castings, for example in cylindrical bars, the test bars which contained ferrite gave values for $\mu < 2$; on the contrary, pearlitic bars gave $\mu > 2$. The coefficient, $\mu$ seemed to indicate, in that case, the difference in structure which results from varying cooling rates and in that way it is able to play the useful role of a structural parameter.

[3] Navarro, J., *"Work on the Mechanical Strength of Irons,"* International Foundry Congress (European), Prague, 1933.

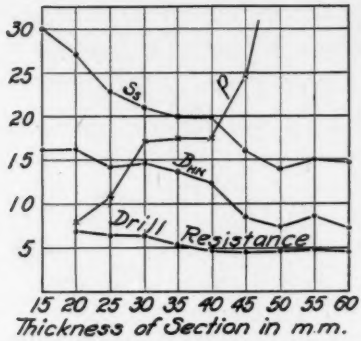


FIG. 5—BRINELL HARDNESS AND SHEAR STRENGTH EXPRESSED AS FUNCTIONS OF THE SECTION.

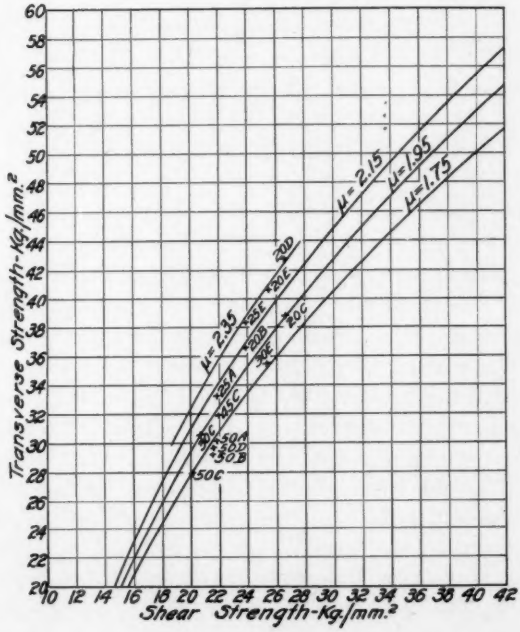


FIG. 6—CURVES OF THE MOST FREQUENT VALUES OF $\mu$.

23. *Relation Between Transverse and Shear Strength.*[2] The coefficient $\mu = \frac{T_f}{T_s}$ and the equation (1) give, on being combined and on putting $T_s$ as a function of $S_s$ (equation 5),

$$(7) \quad S_s = \frac{S_f^2}{\mu \times 49.2} + 11$$

an equality which shows a parabolic relation between $S_s$ and $S_f$. On constructing different curves with the most frequent values of $\mu$ different parabolas are obtained. In the ascending order of the curves are found the finer grained structures and in the descending order, the coarser grain. (Fig. 6.) By taking $\mu = 2$, in even numbers, checking is made easier and the error is insignificant.

## RELATION BETWEEN TRANSVERSE AND HARDNESS

24. *Relation Between Coefficient of Transverse Strength and Hardness.* On combining the equation $\mu = \frac{T_f}{T_s}$ with the equations (1) and (6) there results

$$(8) \quad B_{hn} = \frac{0.14}{\mu} S_f^2 + 65$$

In Fig. 7 we have constructed two of these parabolas corresponding to the parameters $\mu = 1.8$ and $\mu = 2$. This equation shows also the parabolic relation between hardness and transverse strength. The equations which were formerly advanced[4] to describe this relation as probably linear, have only a first approximation value.

25. *Relation Between Work of Rupture and Compressive Strength.* The tests were made in the same Fremont style machine by means of a simple arrangement fitted up by us. The shear test specimens, of which we wished to use portions as specimens for the compression test, had to be reduced in diameter to fit the compressive strength of the machine. Therefore, they were cut down to cylinders 4 mm. (0.16 in.) in diameter and 4 mm. (0.16 in.) in height. All of the 126 test bars were calipered conscientiously, paying special attention to the parallelism of the plane faces where the pressure was brought to bear. The numerical values obtained in these tests are summarized in Table 2.

26. In this set of tests, we were able to obtain another evident and simple relation between the coefficient of rupture and

the work absorbed in rupture. The curve corresponds to the parabola:

$$(9) \quad S_c = 18.725 \sqrt{T_c}$$

Although we have not made tensile tests on the small specimens, we have reason to believe that a similar relation exists there, be-

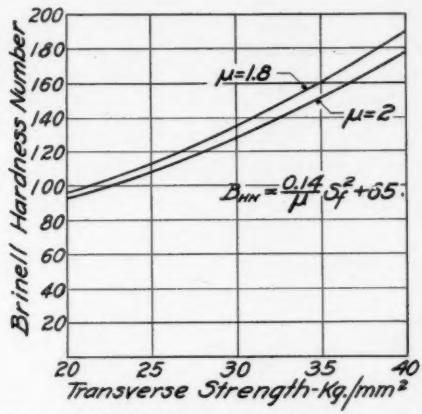


FIG. 7—PARABOLAS SHOWING $\mu = 1.8$ AND $\mu = 2.0$.

**Table 2**

RELATION BETWEEN COMPRESSIVE STRENGTH AND WORK OF RUPTURE

| Test Bar Number | Kgm.† | Kg/mm²* | Test Bar Number | Kgm.† | Kg/mm²* |
|---|---|---|---|---|---|
| 20-A | 15.2 | 72.64 | 35-D | 13.1 | 67.7 |
| 20-B | 14.9 | 72.05 | 35-E | 12.9 | 65.8 |
| 20-C | 23.8 | 88.30 | 40-A | 9.62 | 57.55 |
| 20-D | 19.8 | 84.11 | 40-B | 16.07 | 75.17 |
| 20-E | 22.2 | 88.17 | 40-C | 15.9 | 74.32 |
| 25-A | 15.27 | 71.25 | 40-D | 10.62 | 60.67 |
| 25-B | 18.2 | 78.52 | 40-E | 19.8 | 81.8 |
| 25-C | 14.7 | 71.62 | 45-A | 11.32 | 62.65 |
| 25-D | 15.77 | 73.97 | 45-B | 11.37 | 62.8 |
| 25-E | 17.5 | 77.54 | 45-C | 10.47 | 59.87 |
| 30-A | 16.75 | 71.65 | 45-D | 11.32 | 62.42 |
| 30-B | 11.7 | 64.52 | 45-E | 12.55 | 48.62 |
| 30-D | 15.6 | 73.35 | 50-A | 9.10 | 56.42 |
| 30-E | 14.95 | 72.35 | 50-B | 10.47 | 60.45 |
| 35-A | 12.37 | 64.99 | 50-C | 8.85 | 55.96 |
| 35-B | 13.37 | 67.06 | 50-D | 10.57 | 60.57 |
| 35-C | 15.7 | 73.35 | 50-E | 10.65 | 60.8 |

†Kilogram-meter is 7.2327 ft.-lbs.
*Kg/mm.² is 1422.225 lbs. per sq. in.

cause tensile and compression tests are of the same nature but opposite in direction.

27. *Relation Between Coefficients of Compressive Strength and Transverse Strength. Existence of a Linear Relation of the Form* $S = KS_f$. On dividing the numbers which express the work of rupture by compression and transverse tests, we obtain numbers which do not vary greatly. With our test pieces and ordinary types of cast iron, we obtained the values of Table 3, having an average of 1.28. Now, by combining equations we obtain the following equality:

$$S_c = 2S_f \tag{10}$$

This formula has been checked by us in numerous cases with our

**Table 3**

RELATION BETWEEN WORK OF RUPTURE BY COMPESSION AND TRANSVERSE TESTS

| Diameter of Test Bar in mm. | $\frac{T_c}{T_f}$ | $\frac{T_c}{T_f}$ mean |
|---|---|---|
| 20 | $\frac{19}{14.5} = 1.31$ | |
| 25 | $\frac{16.2}{12.2} = 1.32$ | |
| 30 | $\frac{14.7}{10.8} = 1.35$ | |
| 35 | $\frac{14.4}{10.7} = 1.34$ | 1.28 |
| 40 | $\frac{13.1}{11} = 1.2$ | |
| 45 | $\frac{11.4}{9.1} = 1.25$ | |
| 50 | $\frac{10}{8} = 1.25$ | |

size of test bar and it checks well with experimental results. It is to be expected that with test specimens of other dimensions an expression of this form, but naturally with different constants, exists.

28. *Graph Which Connects Average Values of Work of Rupture by Compression, Shear and Transverse Tests.* Table 4 contains the average values of work, linked with the corresponding diameters of the bars from which the test specimens were cut. In this table are given the average values from 66 transverse,[3] 316

[3] Navarro, J., *"Determination of the Graph 'Hardness-Transverse Strength'."* Anales Soc. de Fis. y Quin., vol. 28, p. 501, 1930. Pearce, J. G., Foundry Trade Journal, Jan. 24, 1929, p. 67.

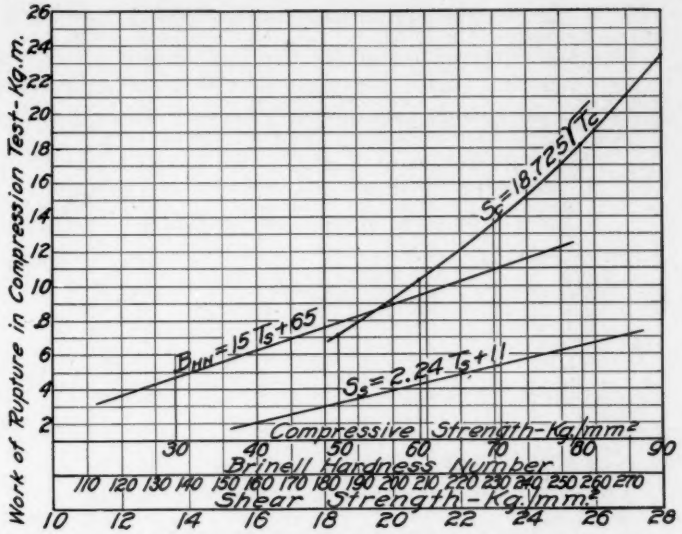


FIG. 8—RELATION BETWEEN BREAKING LOAD AND COMPRESSIVE STRENGTH.

**Table 4**

RELATION BETWEEN WORKS OF RUPTURE

| Diameter of Test Bar in mm. | Transverse Kg-m. | Shear Kg-m. | Compression Kg-m. |
|---|---|---|---|
| 20 | 14.5 | 6.6 | 19.1 |
| 25 | 13.5 | 5.7 | 16.2 |
| 30 | 10.8 | 5.7 | 14.7 |
| 35 | 10.7 | 5.4 | 14.4 |
| 40 | 10.9 | 5.3 | 13 |
| 45 | 9.1 | 4.4 | 11.4 |
| 50 | 8.1 | 4.5 | 9.9 |

shear[2], and 165 compression tests. Fig. 9 contains these average values and the average lines respectively of the relations $T_c$—$T_s$ and $T_c$—$T_f$. From these two it is possible to obtain the relation $T_s$—$T_f$.

29. By the use of this graph, it is possible to simplify in a great measure the mechanical testing of a specimen of gray cast iron, at least inasmuch as it concerns the coefficients, $S_f$, $S_c$, $S_s$ and $B_{hn}$, which are the ones of most interest at present in that material. Concerning elasticity, we have already said sufficient in the paragraph on that subject.

## MANIPULATION TO DETERMINE PROPERTIES

30. *Rapid Information on Mechanical Properties of a Specimen of Gray Cast Iron.* Any transverse, shear or compression test, so that the reading corresponds to its work on the indicator

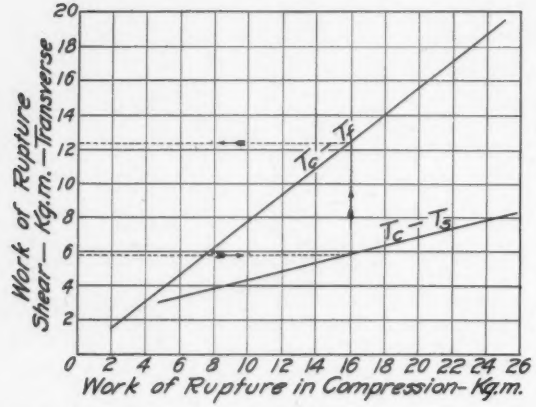
Work of Rupture
Shear — Kg.m. — Transverse
Work of Rupture in Compression-Kg.m.
$T_f$
$T_c$
$T_c - T_s$
0 2 4 6 8 10 12 14 16 18 20 22 24 26
2 4 6 8 10 12 14 16 18 20

FIG. 9—LINES $T_c - T_s$, $T_c - T_f$ AND AVERAGE VALUES OF TRANSVERSE, SHEAR AND COMPRESSION TESTS.

disk of the machine, is able to tell us, by means of the relations given in this paper, what we ought to expect from that specimen in its different mechanical aspects.

31. Starting, for example, with a shear test and taking note of the work of rupture, $T_s$, only, we look up first in Fig. 9 the corresponding value for the work of rupture in the transverse test, $T_f$, seeking the point where the parallel to the abscissa traced from $T_s$ cuts the line relating $T_s$—$T_c$ and going up the ordinate from that point until it cuts the line relating $T_f$—$T_c$, where the intersection gives the value of $T_f$. Already knowing $T_s$, $T_f$, and finding the quotient $\mu = \frac{T_f}{T_c}$, Fig. 2 will give $S_f$ directly and Fig. 8 will give $S_c$. Fig. 6, knowing $\mu$ and $S_f$ gives $S_s$ immediately. Finally, Fig. 7 gives us the Brinell hardness. Consequently $S_f$, $S_c$, $S_s$ and $B_{hn}$ are determined.

32. We are going to give two examples, one a test bar cut from a cylindrical bar 20 mm. (0.79 in.) in diameter and the other a test bar cut from a bar 50 mm. (1.97 in.) in diameter.

Example 1—Test bar 20-A[3]: $T_f$ experimental = 14.

| *Values Found from the Graphs* | *Values Found Experimentally* |
|---|---|
| $\mu = \frac{14}{6} = 2.3$ | ——— |
| $S_f = 39$ | $S_f = 39$ |
| $S_s = 24.5$ | $S_s = 25.7$ |
| $B_{hn} = 150$ | $B_{hn} = 150$ |
| $S_c = 75$ | $S_c = 73$ |

Example 2—Test bar 50-A: $T_f$ experimental = 8.3

| | |
|---|---|
| $\mu = \frac{8.3}{4.5} = 1.8$ | ——— |
| $S_f = 30$ | $S_f = 30$ |
| $S_s = 21.5$ | $S_s = 32$ |
| $B_{hn} = 134$ | $B_{hn} = 144$ |
| $S_c = 60$ | $S_c = 57$ |

33. *The Structural Parameters and Their Mechanical Relations.* We wish to quote a paper of A. Leon[5] which was published a short time ago. In the work mentioned, there is deduced by theoretical and experimental considerations based on the theory of enveloping lines (Hullinie) of Mohr, the relations which connect the different kinds of strength. In order to arrive at these relations, it was necessary, according to the author, to know the coefficients $C = \frac{S_c}{S_t}$ (compressive strength divided by tensile strength). By means of this relation of two strengths one may deduce the coefficient of shear and of torsion. Also, one may deduce for the above mentioned relation the theoretical value of the angles of the slippage planes.

## QUOTES OTHER WORKERS

34. This work is in agreement with ours in that it requires, as our does, the relation between two strength values to determine the different classes of strength. M. Leon says at the end of his work: "One departs from the road when he seeks to deduce the strength in torsion and by shear from the tensile strength alone, or when he hopes to determine the tensile strength from the shear strength. . . . There is no usable general relation between two strength tests. Gray cast iron requires, to establish the characteristics of its strength properties, the guidance of two strength values from which one may deduce, by calculation or graphically, all the others."

[5] Leon, A., *"On the Relation of the Strengths of Gray Iron in Various Tests,"* Die Giesserei, vol. 39-40, p. 429, 1933.

35. Our experimental work confirms the necessity of knowing the relation of two strength values to characterize gray cast iron from different points of view. We have done this by combining each of the penetration strength tests (hardness, shear and compression), with the transverse bending strength. The formulae (7), (8) and (10) show this, (in formula 10, the coefficient $\frac{T_c}{T_f}$ has been taken as a constant equal to 1.28). Then, to obtain the relations between the mentioned characteristics, a structural

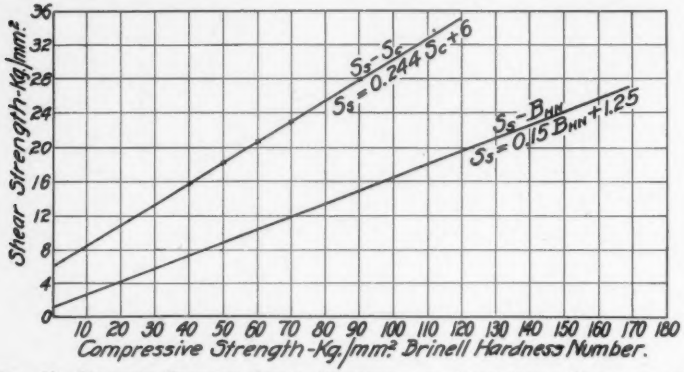


FIG. 10—RELATION BETWEEN SHEAR STRENGTH, AND COMPRESSIVE STRENGTH AND BRINELL HARDNESS.

parameter is necessary which takes into account the phenomena which are produced by the differences in cooling conditions.

## QUOTIENT OF WORK VALUES USED AS PARAMETER

36. Parameter used by us, which is the quotient of the work values, is more convenient than others, for example, that which is obtained by dividing two strength values, because one reads directly from the machine the corresponding values.

37. The knowledge from a graph of one coefficient after having determined another (for example, $T_s$ as soon as we know $S_s$), permits the setting up more rapidly and certainly the graphs of the envelopes of Mohr because the measurement of the angle of the plane of slippage may be dispensed with, a measurement which is frequently not able to be made with accuracy.

38. *Relation Between Peneration Tests (Compression, Hardness and Shear).* Fig. 8 shows the three graphs of the coefficients of compression, hardness and shear combined as a function of their work of rupture. On combining the correlating values of these

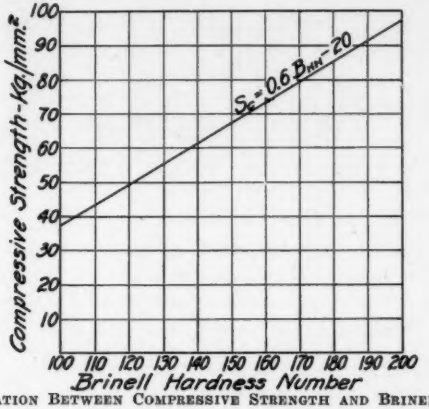


FIG. 11—RELATION BETWEEN COMPRESSIVE STRENGTH AND BRINELL HARDNESS.

graphs, we have obtained Figs. 10 and 11, which connect these coefficients. The corresponding formulae are:

$$(11) \quad S_s = 0.244\,S_c + 6$$
$$(12) \quad S_s = 0.15\,B_{hn} + 1.25$$
$$(13) \quad S_c = 0.6\,B_{hn} - 20$$

These formulae, independent of the work of rupture, describe the relation between the tests, compression, hardness and shear, which we call penetration tests. The existence of straight line relations, constant angular coefficient, explains the parallelism which was noted in comparing the tests mentioned. These formulae, in addition to those previously given, have enriched and made easy the rapid testing of gray cast iron, the original object of this work.

## APPENDIX I

### MEANING OF SYMBOLS

$S_f$—Transverse strength.
$S_s$—Shear strength.
$S_c$—Compressive strength.
$T_f$—Work of rupture in transverse test.
$T_s$—Work of rupture in shear test.
$T_c$—Work of rupture in compression test.
$C, H$—Constants.
$p$—Tangent of the angle at the point of rupture in stress-strain transverse diagram.
$B_{hn}$—Brinell hardness number.
Kg/mm²—1422.225 lbs. per sq. in.
Kgm.—7.2327 ft. lbs.

# Steel Castings*

By W. H. Hatfield,† D. Met., Sheffield, England.

**Abstract**

*The Steel Foundry Industry in Great Britain is fortunate in having highly skilled workmen with long traditions and an excellent supply of shrewd, practical managers and foremen. The English foundries also have a greater diversity of design and a larger number of oddment orders than do American foundries, according to the author. Although much progress has been made in research many difficulties are still to be overcome. An interesting problem as yet unsolved is the apparent fact that fluidity at times appears to be influenced by the physical chemistry of steelmaking and to be, in a measure, independent of the actual temperature. The effect of methods of deoxidation and oxygen content of steel are being studied and progress is being made. Research also is being conducted into the properties and applications of various refractory materials as molding materials. The author outlines briefly the application of the various melting processes to steel casting manufacture and gives some points on the properties of foundry sands, cores, and molding problems. Casting conditions and the use of feeder heads receive comment. The author then gives several examples of the proper application of feeder heads to produce sound castings even where the variation in section is considerable. The latter portion of the paper is devoted to a description of the investigation of a turbine casing casting cast from mild steel. The author traces the molding and core making practice applied to this particular casting and shows by means of diagrams the location of feeder heads. The casting required 20 feeder heads of various sizes. He also gives the heat treating procedure accorded the casting and by photographs of macrostructures in various locations, shows the casting to be free from shrinkage defects. In the last section of the paper, the author shows several photomicrographs of various types of steel made in Great Britain*

* Annual Exchange Paper from the Institute of British Foundrymen.

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Note: This paper was presented at a session on Steel Founding at the Fifth International Foundry Congress and the 1934 Annual Convention of A.F.A. held in Philadelphia.

*both in the as cast and the heat treated condition. These micrographs may be used to compare results obtained in America with those in Great Britain.*

1. The object of these exchange papers is to obtain some comparison as regards the outlook, methods and results of practice in our respective countries. The author's very interesting and pleasant experiences during visits to the United States of America, caused him to accept with much appreciation the invitation to present this paper.

2. Foundries in Great Britain are fortunate in several respects. They have highly skilled workmen with long traditions in the trade, and an excellent supply of shrewd and practical managers and foremen. The demands upon our foundries differ in measure from the demands upon many American foundries principally in the greater diversity of design of casting and the larger number of oddment orders. Those factors call for great skill and resource on the part of our staffs and workmen.

## VARIETY OF CASTINGS MADE

3. An individual foundry is frequently called upon to produce a wide range of castings; castings for turbine construction, railway castings, dredging machinery, ships castings, castings for agricultural machinery, for chemical plants, pump and valve parts, not to mention the vast range of general engineering castings. Such a wide range demands the use of many different steels with necessary metallurgical and metallographic knowledge on the part of the management.

4. The art of making steel castings has reached a very high standard. It is, of course, well known and appreciated that if everything is subordinated to the production of a perfect steel *ingot,* i.e. simplicity in design of mold and feeder head, control of casting temperature, speed of teaming, not to mention the provision of perfectly "killed" liquid steel, even so, perfection is difficult of attainment. Therefore, when the designer sits down in his drawing office and presumes to prepare drawings of the finished shapes in which the steel has to do service, and then expects the foundrymen to cast these parts into their final shapes, he can only be saved from trouble by the art of the foundryman.

5. The designer always asks much of the foundryman. Sometimes he asks too much. No one should presume to design steel castings unless he has had adequate foundry experience. How-

ever, whatever complexity of design or changes in section there may be in the casting required, the foundryman is expected to, and usually does, produce a reasonably good casting by arranging the suitable number and form and position of gates and feeders, suitable position of mold, and correct nature and condition of the refractories used for mold and cores.

## NEED FOR RESEARCH

6. The need for research in steel founding has long been appreciated in Great Britain, and the larger companies have their own research laboratories. The Brown-Firth Research Laboratories, which the author has the pleasure of directing, was in full operation as long ago as 1908. Of later years, however, co-operation in problems affecting the whole industry has developed and for some few years now, the Steel Castings Committee, a technical committee of the British Federation of Iron and Steel Manufacturers, has been doing very useful work. Its first report was issued in 1933 (Iron and Steel Institute).

7. While the steel founder is very successful in most instances, it is appreciated that his practice is, even yet, necessarily based upon an empirical handling of a large number of acquired data in the light of practical experience in the foundry. The accumulation of exact knowledge as years pass is gradually changing the "art" into the "science" of steelfounding. Research into many of the obvious problems is not easy, owing to the difficulty of experimenting as regards the physical chemistry of steelmaking and the determination of physical and mechanical values at the high temperatures involved. However, much progress is being made.

8. One interesting problem, as yet unsolved, is the apparent fact that fluidity at times appears to be influenced by the physical chemistry of steelmaking and to be, in measure, independent of actual temperature. No adequate means of determining fluidity against an absolute standard has yet been devised, while the effect of temperature on the true viscosity of molten steels has not been determined.

9. The effect of methods of deoxidation and of the oxygen content are now being studied in a promising manner both at Sheffield University and at the National Physical Laboratory. Invaluable work is proceeding on behalf of the Steel Castings Committee at Woolwich Research Laboratories on the strength of

steels subsequent to freezing. The properties and applications of various refractory materials as molding material is now receiving attention on lines not hitherto attempted. In this short paper, however, the author can best deal with present steel founding practice.

## MANUFACTURE OF THE STEEL

10. While the open-hearth process is used, particularly for the larger castings, the electric processes are being extensively applied particularly for smaller castings. Considerable tonnage also is being produced from small converters. As regards the smallest of castings, the crucible process is still regarded as effective. The process employed is determined largely by the composition of the steel and the nature of the castings. Except to state that, whatever the process, the steel must be of the dead-killed or piping type, it is unnecessary to deal further with that aspect of matters on this occasion.

## SAND REQUIREMENTS

11. The essential properties required of sand are refractoriness and porosity. As regards preparation, correct grading and control of moisture content are essential. Systematic handling is the only means for ensuring consistent results, which demand uniform qualities both chemically and mechanically. The use of a suitable proportion of old sand is not only feasible but very satisfactory and economical, but the practice in this respect must be, and is, carefully planned and recorded.

12. From this point of view, a foundry working on repetition work, producing large quantities of castings to a particular pattern, has a great advantage, since the preparation of the sand can be systematized on a much simpler scheme than in a foundry which produces castings of miscellaneous types. At the same time, the foundry of the latter type has greater facilities for studying the response of different mixtures to the varying factors, and therefore is better able to make a suitable selection when a new type of casting is to be made.

13. Permeability and strength data are given in various publications and need not be discussed here. While such data are of great value, it is necessary in all cases to obtain direct practical experience as to the suitability of any molding material for particular purposes.

14. The cost of sand per ton of finished castings is naturally an important factor in the cost of the casting, and necessitates a careful study of market prices of the available sands.

15. The variables in castings which affect the properties required in the sand, are such items as deep or shallow molds, molds with large surface area in the upper portion, simple or intricate form of mold, molds for light or heavy sections, as well as the quality of steel to be cast.

16. Light castings usually can be made satisfactorily in a naturally bonded sand such as Yorkshire or Belgian yellow sand. The resulting floor sand is satisfactorily reconditioned and added to the new sand in substantial proportions, say 20 to 40 per cent, according to the work on hand. Such sand mixtures are fairly uniform and consistent with about 15 minutes milling. When the moisture content is suitably controlled for green or dry sand work, they are found to give good all round results. Additions of washed silica sand have the advantage of increasing permeability and refractoriness. It is sometimes found to be an advantage to employ a green sand for the lower part of a mold, and an oil sand, dried, for the upper portion.

17. The influence of the type of steel used for the required castings is illustrated by comparing ordinary mild steel either with high-manganese steel or high-chromium steel. Manganese steel has a great erosive action and flows easily, while chromium steels tend to be somewhat sluggish.

18. "Compos" used in special cases, consisting of clay and other constituents, such as crushed silica bricks, old pots, common clay, and china clay together with coke dust, are introduced in various forms and proportions. The aim, whether with sand or "compo," is to obtain a material which, at high temperature and load pressure, has sufficient refractoriness to retain its shape and not become fused and at the same time is permeable.

## PROPERTIES OF CORES

19. Cores must have the property of collapsing readily after the steel is solid, as otherwise pulling stresses are set up by the contraction in the metal around them immediately after freezing. Mild steel solidifies quickly, and the collapse of the core due to contraction must take place without delay if hot pulls are to be prevented. Silica sand of medium grain, bonded with a suitable

oil, serves well for this purpose, but the degree of baking requires careful control. Some stiffening of the core to help it to retain its shape may be necessary in some cases, and an addition of resin to the mix may be employed for this purpose.

## MOLDING PROBLEMS

20. The molder's art is the determining factor in obtaining consistently good castings. Long years of careful training are necessary for molders and many of them have an astonishing intuition based upon long practical experience and observation.

21. In molding, it is particularly important to reproduce the correct degree of ramming. While for repetition work, machine molding properly controlled eliminates some of the variables due to the human element, the special type of steel foundry work with which the author is chiefly connected does not lend itself to any great degree to mass production by machine methods.

22. Planning, as regards fixing of cores and provisions for venting, should be done jointly between those responsible for the different phases of the job. Free passage of air expelled from the sand by expansion effects must obviously be provided in an outward direction. The permeability of the backing sand is equally important to that of the facing sand. This is obviously of special importance in green sand work due to the heavier generation of steam. The correct use of brackets calls for discrimination and should be decided beforehand with full appreciation of the features of the particular casting. The same remarks apply equally well to core-irons.

23. The strength of the mold and mold-box acquires a greater significance when dealing with castings having large vertical dimensions. The "ferrostatic" pressure due to the head of fluid metal, being nearly eight times that for the same head of water, quickly reaches serious values. With large castings, and castings of tubular shape, it is not uncommon to have a depth of 30 ft. of metal to take care of. In the case of castings of large horizontal projected area, although the fluid pressure per unit area may be not unduly large, the total upward pressure on the mold-covers reaches colossal values and demands heavy weighting suitably distributed since any movement in the parts of the mold, during casting, readily wrecks a costly casting.

24. Perhaps the most serious question in the foundry in the production of sound castings is that of satisfactorily arranging for

free contraction during cooling, particularly in the early stages just after casting. There are two separate factors entering into the phenomenon of "pulled" castings. These are: (1), the strength of the refractories whose natural thermal contraction is almost negligible in comparison with that of the steel, and which are generally still heating up and expanding while the steel is solidifying and contracting, and (2), the unequal cooling of the casting, causing some parts to be contracting much in advance of others which may be at a more tender stage as regards temperature.

25. While item (1) is largely a question of the correct choice of sands, item (2) brings in the question of design of the casting itself. The amount of contraction of large steel castings is very substantial. A usual allowance for carbon steel castings is 5/32 to 7/32 in. per foot. This leads to a total contraction on a ship's casting—say on stem pieces or stern frames of 30 to 40 ft. in length—of nearly 8 inches. It is necessary in such cases to construct the mold so that it can be liberated at different stages to prevent the casting from pulling itself to pieces.

26. The most vulnerable positions are those which are last to cool, such as thick portions or the junctions of cross ribs. The practice of adding thin brackets to protect such positions is successful in some cases, but, as already mentioned, requires judicious application. If overdone, it may be the cause of trouble instead of the cure.

### USE OF CHILLS ADVANTAGEOUS

27. The use of "chills" to accelerate the cooling of certain portions of the casting is advantageous in many cases but, like the use of brackets, requires careful judgment in its application. It has been shown that by the use of chills the danger of hot pulls may be transferred from one position in a casting, which would have been vulnerable since it would have been the last to freeze and would have suffered at that time from contraction effects which were applying tension from the neighboring solid material, to another position less affected by such conditions. If, however, the effect is merely to transfer the pull to a position equally likely to suffer, no advantage results.

28. As regards the later period during cooling, it is a curious fact that cracks appear liable to develop at a temperature not far removed from the "blue brittle" range, say 300 degrees Cent. (572 degrees Fahr.) in plain carbon steel. These are clearly

due to the production of internal stress due to differential cooling of the mass, and whereas the material down to a temperature of a dull red heat—say 500 to 550 degrees Cent. (932 to 1022 degrees Fahr.)—has some capacity for yielding under such stresses, this yielding property is known to be present to a much smaller degree round about 300 degrees Cent. (572 degrees Fahr.) or at lower temperatures. This presumably accounts for the apparent critical nature of the "blue" range of temperature. For special qualities of steel, this critical range may occur at higher temperatures. A suitable control of cooling conditions and correct interposition of heat-treatment is the method generally employed to overcome the danger of "cold" cracks. Frequently, much can be done by small modifications in design to reduce both hot pulling and cold cracking dangers.

## CASTING CONDITIONS

29. Little need be said about the actual casting operations. The transfer of metal from furnace to mold requires adequate plant for manipulation. Avoidance of the inclusion of slag and foreign matter in the mold obviously is necessary, and the need for the employment of sufficiently high metal temperature to give the necessary fluidity without undue superheat, is readily appreciated by those in charge of casting operations. The molten metal should be run into the mold as quickly as is consistent with a proper flow and adequate control.

## FEEDER HEADS

30. The choice of the number, form, and spacing of the position of feeder heads on a casting is the great responsibility in the production of the majority of steel castings if a satisfactory, solid product is to be obtained. The freezing of any section naturally proceeds from the outer surface inward, and the inner portion thus has to suffer the combined liquid and solid contraction after the outer solidified portions are more or less set in position.

31. The natural tendency to form a "cavity" must be met by having an adjacent supply of hot fluid metal which can run into the desired position in sufficient quantity to prevent the formation of a cavity. All feeder heads should be applied in such positions that no contracting inner part of the casting is denuded of metal. The thinner portions naturally tend to draw from the thicker portions, and junctions of ribs and cross members, which

lag slightly behind the neighboring parts in cooling, are liable to have their centres "sucked."

32. Feeder heads must be sufficiently numerous to feed all points where such a tendency may exist. Modifications in design frequently can remove danger points, since thin and thick sections in juxtaposition are naturally not ideal from the foundry point of view, however desirable they may be as regards the purpose of the designer. Clear judgment and appreciation of the natural course of flow of the metal in the molds and of the order of freezing is required. In a composite casting, each section generally demands separate feeding.

33. The suitable form and size of feeder heads are best appreciated by sectioning examples of different types. Several cases are indicated later in the paper. In addition to having sufficient "body" of metal, feeders must be of such dimensions that the central pipe or cavity which forms in them does not extend into the actual casting. Long thin heads fail in this way, and actually bring added weakness by freezing across near the outside, and thus causing a deep seated inner and discontinuous pipe. It will be appreciated that in a steel ingot, where conditions are favorable, a reasonable weight of feeding head is very necessary. In steel castings, even as much as 40-50 per cent weight of feeding heads may be necessary, according to the form of casting.

34. Mention has already been made of "contraction" effects and the advantages, where possible, of hot stripping. As soon as possible after stripping, loose sand should be removed from the casting. The casting then should be placed in the annealing furnace.

## EXAMPLES OF CASTINGS

35. The state of the foundry "art" can best be judged by sectioning a variety of castings. The castings examined have been taken from the steel foundry operated by the company with which the author is associated and in each case it must be said that the production is the result of considerable experience on the part of the foundry staff and operatives.

36. Impellers are difficult castings to make but in Figs. 1 and 2 will be found photographs of one cast in stainless steel and also a view after sectioning. These illustrations show that feeding has been successfully accomplished. In Fig. 3 will be found portrayed a 7½-ton cast mild steel vessel after sectioning transversely

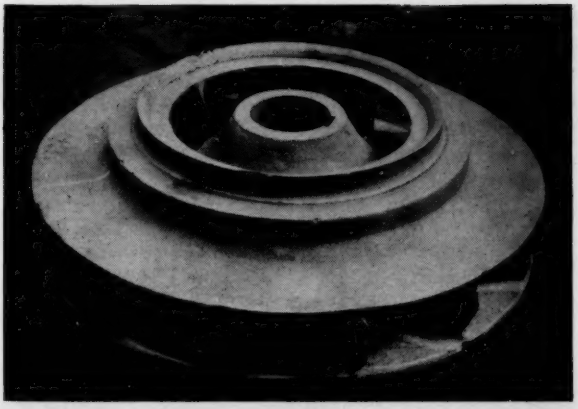


FIG. 1—(ABOVE) STAINLESS STEEL IMPELLER. FIG. 2—SAME CASTING SECTIONED TO SHOW THE SOLIDITY OBTAINED BY PROPER FEEDING.

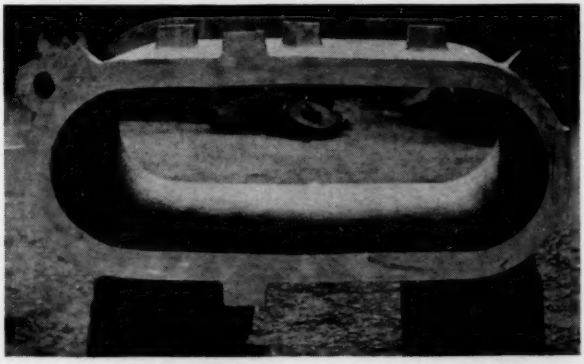


FIG. 3—A 7½ TON MILD CAST STEEL VESSEL AFTER SECTIONING TRANSVERSELY AT A POINT ABOUT ONE-THIRD OF ITS LENGTH.

at a point about one-third of its length. In Fig. 4 will be seen the result of sectioning a 0.40 per cent carbon rotary cast steel gear blank, a particularly difficult job to cast sound.

37. Figs. 5 and 6 represent a stainless steel Pelton wheel bucket before and after sectioning. In this case, the changes in section presented a most difficult task from the point of view of overcoming local shrinkage defects. In Fig. 7 will be found reproduced an indication of the freedom from shrinkage effects obtained in manganese steel dredger bucket practice, after testing and sectioning.

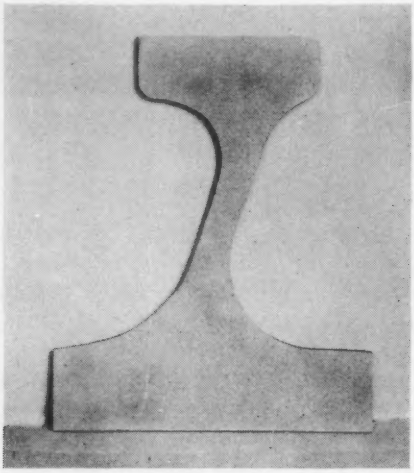


FIG. 4—SECTION OF A 0.40 PER CENT CARBON ROTARY CAST STEEL GEAR BLANK. THESE CASTING ARE PARTICULARLY DIFFICULT TO CAST SOUND.

38. Lastly, in Fig. 8 will be found a photograph of a turbine casing cast in mild steel. This instance might be used to discuss the foundry technique which is employed to ensure soundness in such complex and difficult castings.

39. This was a turbine steam end casing (top half) with inner chamber 5 ft. 5 in. in diameter and external dimension 5 ft. 6¾ in. x 9 ft. 4 in. horizontally and a depth of 6 ft. 2 in. The net weight as delivered after rough machining was just over 13 tons. The general form as well as details is given in the four drawings shown in Fig. 10. It will be seen that the inner chamber is connected with the upper horizontal valve chest by a num-

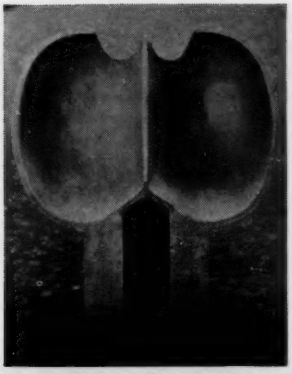


FIG. 5—(ABOVE) CAST STAINLESS STEEL PELTON WHEEL BUCKET. FIG. 6—SAME BUCKET AS IN FIG. 5 SECTIONED. VARIATIONS IN SECTION THICKNESS PRESENT A DIFFICULT PROBLEM IN OVERCOMING LOCAL SHRINKAGE DEFECTS.

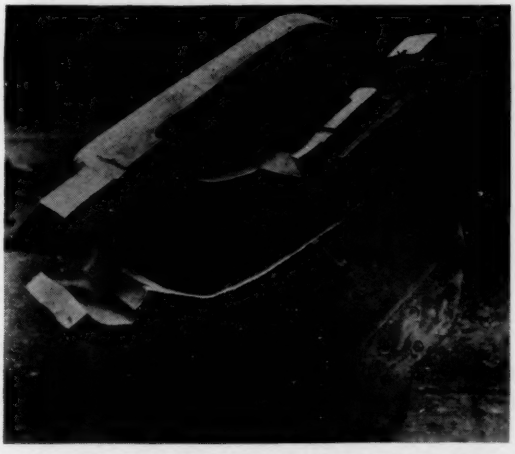
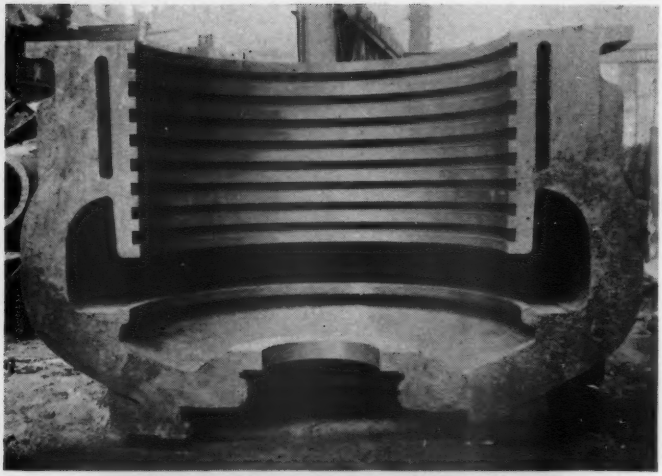


FIG. 7—AUSTENITIC MANGANESE STEEL DREDGER BUCKET AFTER SECTIONING ILLUSTRATING THE FREEDOM FROM SHRINKAGE DEFECTS POSSIBLE BY PROPER FOUNDRY PRACTICE.



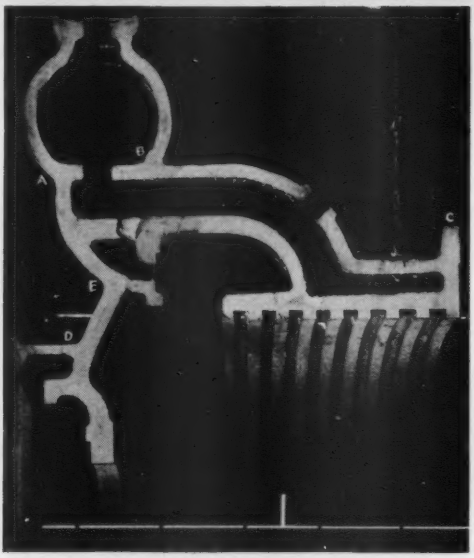



FIG. 8—(ABOVE) TOP HALF OF A CAST MILD STEEL TURBINE CASING. THE CASTING HAS BEEN ROUGH-MACHINED. FIG. 9—SAME CASTING AS IN FIG. 8 SECTIONED TO SHOW SOLIDITY. A, B, C, D, AND E IN THE ILLUSTRATION WERE ETCHED TO BRING OUT THE MACROSTRUCTURE.

ber of distributed steam passages and that there are various cavities (giving the equivalent of a double wall) fed by steam. Bot-

tom and end flanges are incorporated in the casting, as well as several projecting inner portions. Stiffening ribs are attached at various points.

40. For this casting, mold and cores were constructed entirely of a "compo" of old pots, silica bricks, sand, china clay and coke breeze well ground. The facing in the mold was 3 to 4

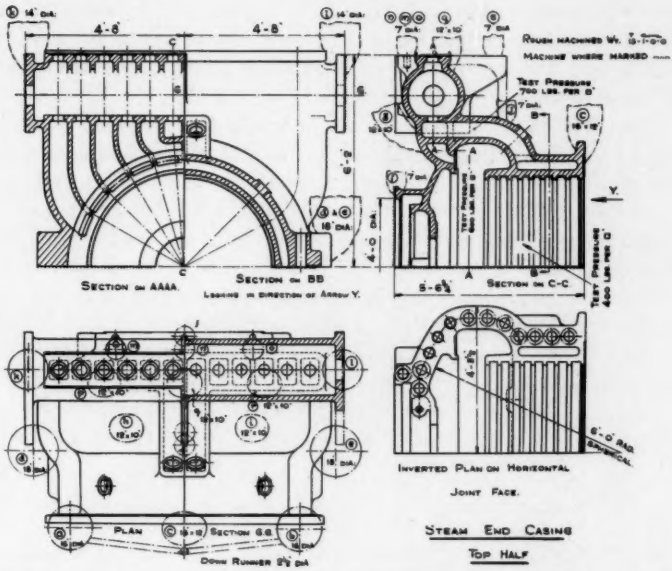



FIG. 10—DRAWING SHOWING DIMENSIONS OF TURBINE CASING AND SIZE AND LOCATION OF FEEDER HEADS.

in. deep, the backing being in floor-sand. For the cores the facings were up to 3 in. thick for the larger ones and about 1 in. for the steam passages, the core-centres being coke-ashes, etc. The mold was rammed up and divided into sections for convenience in drying and in placing the cores. The total number of "drawbacks" was 10, and the number of cores, 19. Drying was carried out at approximately 320 degrees Cent. (608 degrees Fahr.) for periods up to 48 hours, according to size. After the cores had been partly dried, and while they were still warm, the surfaces were sprayed with tar. The cores then were given a further drying period.

41. The steel was melted in an acid Siemens furnace, the actual analysis being:

Carbon, per cent.....0.18
Silicon, per cent.....0.38
Manganese, per cent.....0.75

The charge was of about 67,200 lbs. The casting temperature was 1570 degrees Cent. (2858 degrees Fahr.) and the metal was cast simultaneously through two 1¾-in. nozzles in the same ladle.

42. Further metal (about 2800 lbs.) was added to all the top "heads" on the casting about 1 hour after casting, this metal being taken from a separate furnace.

43. The metal was run simultaneously through two vertical runners 2½ in. diameter, via the bottoms of two heads *a* and *b*, Fig. 10, situated near the outer covers of the large end-flanges of the casting. The runners were constructed of fireclay runner-sleeves. The heads *a* and *b*, which were totally enclosed by compo, were of 16 in. diameter and were connected to the mold through suitably radiused passages. These heads were stopped off at a 3 ft. height except for central 3 in. passages at the top.

44. Other heads provided on the casting, shown in Fig. 10, were as follows:

*c* .....16 x 12 in., oval, at the crown of the end flange.
*d* and *e*.....18 in. diameter, over bottom flange at the ends of the casting, not far from the vertical central plane.
*f* .....7 in. diameter on gland face.
*g* .....12 x 16 in., oval, on the same level as *c*, placed at centre of casting just below the horizontal valve box.
*h* and *i*.....12 x 10 in., oval, 1 ft. 7 in. each side of centre of casting as indicated, feeding the rib projecting portion of the inner cylinder.
*j* .....A small head, 7 in. diameter, over central rib at the top.
*k* and *l*.....14 in. diameter heads over flanged ends of top valve box.
*m*, *n*, *o*, *p*, *q* and *r*....oval heads, 12 x 10 in., over bosses and valve box.
*s* and *t*.....Heads 7 in. diameter over extending upper portion.

45. Thus there were 20 heads. The gross weight of the casting including heads was 56,500 lbs., the weight after removal of heads but before machining 31,920 lbs., and weight as supplied to the turbine builders, 29,232 lbs.

46. The casting was eased in the mold round the feeder heads within 2 hours after casting, but otherwise cooling was allowed to proceed without interference for a period of 9 days, by which time the temperature throughout was at about 100 degrees Cent. (212 degrees Fahr.) It was then roughly dressed. The smaller

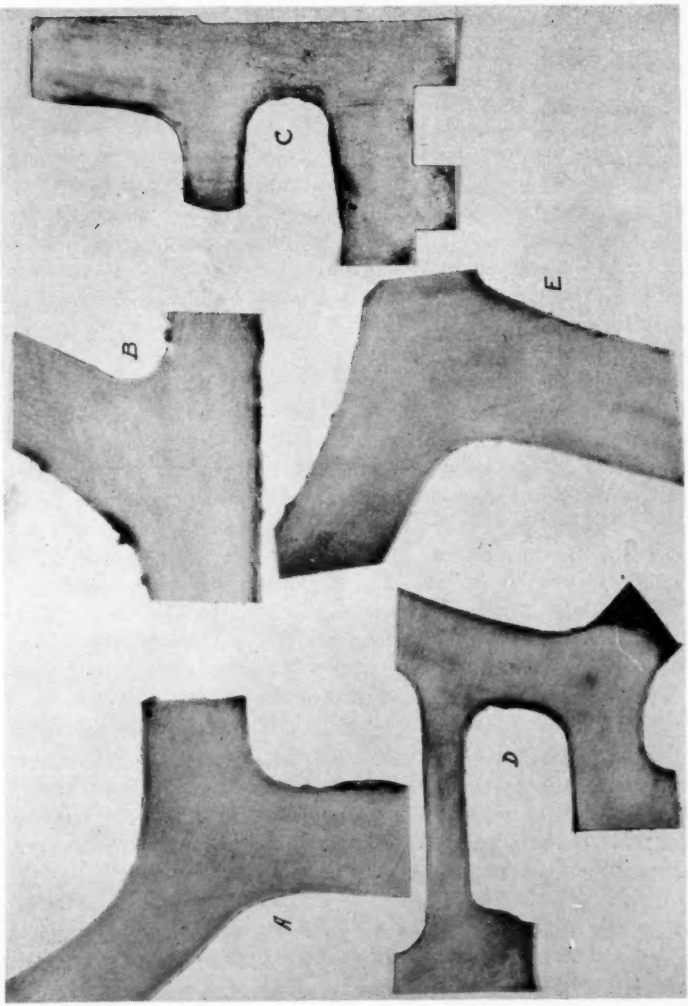



FIG. 11—MACROSTRUCTURES OF SECTIONS A, B, C, D AND E, FIG. 9.

heads at this stage were partially removed, and the larger heads cut away by the oxy-acetylene flame to within about 2 in. of the casting proper, the object being to minimize the effect of heavy masses during heat-treatment. All cores were loosened but not completely removed. The residue of sand in certain portions, e. g., steam passages, had the advantage of lessening scaling during heat-treatment.

47. The casting was placed in the practically cold annealing furnace and was heated up slowly with the furnace. The furnace was producer-gas fired and the heating up occupied a period of 30 hours. The upper limit of temperature of heating was 900 degrees Cent. (1652 degrees Fahr.). After maintaining the casting at this temperature for 24 hours, it was allowed to cool slowly in the furnace to 600 degrees Cent. (1112 degrees Fahr.) and was then slowly reheated to 750 to 770 degrees Cent. (1382 to 1418 degrees Fahr.), held for 16 hours and finally cooled in the furnace very slowly. The heat treatment covered a total period of 14 days.

48. The casting was then rough machined, fins etc. removed, and a further low temperature annealing treatment given. The temperature was 650 degrees Cent. (1202 degrees Fahr.) and the total period occupied, including heating and cooling, was 6 days.

49. Finally, the casting was dressed, chiefly by shot-blasting, and was then ready for delivery.

50. In Fig. 8 will be found a photograph of the rough-machined casting. This was now sectioned and the disclosed surface is seen in Fig. 9. It will be seen that the internal metal is free from any shrinkage or other defects. The plane of sectioning can be readily determined from the drawings in Fig. 10.

51. The surface exposed by the sectioning was now prepared in the usual way and then etched to bring out the macrostructure. Fig. 11 shows the structures as developed at the five positions *A*, *B*, *C*, *D* and *E* as indicated in Fig. 9. It is clear that the feeding arrangements have operated successfully. Test-pieces cut from the casting in its final condition gave the following results:

| | *A* | *B* |
|---|---|---|
| Tensile Test, Yield Point, tons per sq. in..... | 16.0 | 16.5 |
| lbs. per sq. in..... | 35,840 | 36,960 |
| Max. Stress, tons per sq. in..... | 31.4 | 31.7 |
| lbs. per sq. in..... | 70,336 | 71,008 |
| Elongation, per cent. in 2 inches | 32.0 | 30.0 |

Bend tests—180 degrees without cracks on ¾ x ⅜ in. section.

52. Steel castings require heat-treatment to put them into a "serviceable" condition from several points of view:—(1) To liberate casting stresses, (2) To break down the casting structure, (3) To give the material the most suitable hardness and mechanical properties for the particular purpose it has to serve.

53. As regards (1), a sufficient treatment would be a period of "soaking" at a temperature at which the casting is slightly plastic, followed by slow cooling. In the case of mild steels, a temperature of the order of 650 degrees Cent. (1202 degrees Fahr.) would be sufficient. It is essential, however, that heating up to the maximum temperature should be at a sufficiently slow rate to avoid the superposition of heating up stresses, since in general these would be additive to the stresses left in after casting, and would tend to cause "clinking." In large castings, this is a very serious danger.

### BREAKS DOWN STRUCTURE

54. As regards (2), the system of crystallization formed in the steel when solidifying is usually not only coarse but of somewhat acicular form, and tends to a deficiency in ductility if not actual brittleness. Naturally, the degree to which this exists varies very much with the type of steel, as well as with the size of casting and casting temperature. A prolonged heating, at a temperature well above the upper critical point of the steel, applied to the casting gives opportunity for diffusion of the constituents which form a solid solution at high temperatures and subsequent cooling provides for recrystallization resulting in a refined structure. This treatment for most castings can be combined with (1) as indicated by the example quoted later.

55. This aspect of heat-treatment is successfully dealt with for mild carbon steel castings without difficulty and resulting mechanical tests are of a high order. In the case of alloy steels, particularly the richer alloy steels of fairly high carbon content,—e. g. 3 per cent chromium, 0.9 per cent carbon,—the diffusion of carbides is a much slower procedure, and extended annealing periods may be necessary. The necessary times and temperatures to give the desired result for each type of steel can only be arrived at by experience.

56. With regard to (3), it will be appreciated that while many castings are in their most satisfactory condition for service in the annealed condition, there are many special purposes for

which a somewhat higher hardness is desirable. Carbon steel castings are given a slightly higher hardness by normalizing—air cooling from above the recalescence point—instead of annealing. Certain alloy steels, e. g. nickel-chrome, or nickel-chrome-molybdenum steels, may after annealing, be given a hardening and tempering treatment, while "austenitic" alloy steels, such as 12 per cent manganese or high chromium-nickel stainless steels, require putting into the true austenitic condition, which demands a rapid cooling from a fairly high temperature.

57. It will be appreciated that the application of any drastic "cooling" treatment to a casting is liable to set up serious stresses during and after such treatment, and discrimination is required in deciding whether such treatment is a safe procedure, having in mind the size and form of the casting. In any case, except for the austenitic steels, a suitable reheating or tempering treatment should follow any hardening or quenching, so as to minimize residual stresses as well as to remove brittleness and lack of uniformity in hardness.

58. As in the case of the heat-treatment of forgings, the pieces require adequate supporting and should be handled so as to prevent distortion, either while hot, or during heating and cooling.

59. In Table 1 will be found the results of different heat-treatments on two examples of cast material in carbon steel. The carbon contents are respectively 0.11 per cent and 0.29 per cent.

60. In Figs. 12 and 13, typical photomicrographs are given of the "as cast" and heat-treated condition of steel castings of different compositions, so that, metallographically, comparison can be made with present American practice.

## General Comments

61. The author trusts that, so far as the limitation of space in this short paper permits, a useful account has been given of the points of view of the British steel founder. Much more space could be given to the single phase of feeding and making sound, but it is hoped that sufficient data have been given.

62. It must, of course, never be forgotten that a steel casting is not a steel forging. The latter is based on an ingot, the production of the soundness of which has been the first consideration; simple in design, narrowest section at the bottom, greatest sec-

**Table 1**

**EFFECT OF VARIOUS HEAT TREATMENTS ON TWO MILD CAST STEELS**

| Analysis per cent | | | | | Heat Treatment | Mechanical Tests | | | |
|---|---|---|---|---|---|---|---|---|---|
| C. | Si. | Mn. | S. | P. | | Y.P. Tons/ sq. in. | T.S. Tons/ sq. in. | Elong. Per Cent | Red. of Area Per Cent |
| 0.11 | 0.27 | 0.33 | 0.04 | 0.03 | As Cast. | 14.8 | 29.7 | 17 | 24 |
| | | | | | 890/900°C., 10 hrs. Air cooled. | 14.4 | 28.0 | 38 | 66 |
| | | | | | 890/900°C., 10 hrs. A.C. reheated 600°C. 2 hrs. | 12.8 | 25.6 | 38 | 64 |
| | | | | | 890/900°C., 10 hrs. cooled to 600 raised 770°C. 6 hrs. cooled slowly. | 13.6 | 26.0 | 39 | 66 |
| | | | | | 890/900°C., 10 hrs. W.Q. T 600°C. 2 hrs. | 16.4 | 27.6 | 38 | 61.6 |
| 0.29 | 0.24 | 0.81 | 0.03 | 0.03 | As Cast | 19.6 | 35.2 | 10.0 | 12.0 |
| | | | | | 890/900°C., 6 hrs. A.C. | 22.4 | 37.6 | 20 | 27.6 |
| | | | | | 870/880°C., 20 hrs. A.C. | 22.0 | 35.2 | 26 | 30.8 |
| | | | | | 840/850°C., 8 hrs. cooled to 600/620 held 4 hrs. and slow cooled. | 21.6 | 34.0 | 17 | 21.6 |
| | | | | | 890/900°C., 6 hrs. A. C. reheated 630. 2 hrs. Furnace cooled. | 22.0 | 37.2 | 23 | 30.8 |
| | | | | | 890/900°C. 6 hrs. cooled 600/620°C. 2 hrs. held and cooled very slowly in sand. | 17.6 | 33.2 | 30 | 44.8 |
| | | | | | 870/880°C. 20 hrs. cooled to 600°C. reheated 770°C. 6 hrs. Air cooled. | 21.9 | 35.0 | 25 | 36.3 |

tional area at the top and the ingot proper having superposed upon it an adequate refractory lined feeder head.

63. On the other hand, as regards castings, the designer pro-

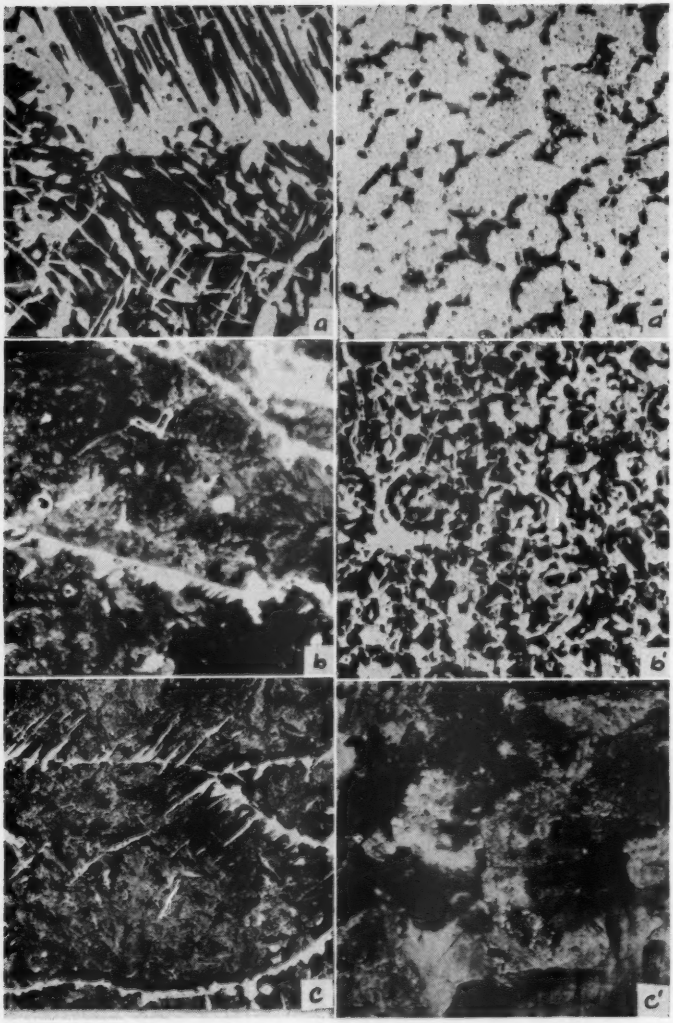



FIG. 12—(a), PHOTOMICROGRAPH OF 0.20 PER CENT CARBON CAST STEEL, AS CAST, MAGNIFICATION, 50x; ($a^1$), SAME STEEL REHEATED TO 900 DEGREES CENT. (1652 DEGREES FAHR.) FOR 2 HOURS AND AIR COOLED. MAGNIFICATION, 50x; (b), PHOTOMICROGRAPH OF 0.40 PER CENT CARBON CAST STEEL, AS CAST. MAGNIFICATION 50x; ($b^1$), SAME STEEL REHEATED TO 900 DEGREES CENT. (1652 DEGREES FAHR.) FOR 2 HOUR AND AIR COOLED. MAGNIFICATION, 50x; (c), PHOTOMICROGRAPH OF A 0.51 PER CENT CARBON, 1.0 PER CENT CHROMIUM, 0.64 PER CENT MANGANESE CAST STEEL, AS CAST. MAGNIFICATION 50x; ($c^1$), SAME STEEL ANNEALED, REHEATED TO 850 DEGREES CENT. (1562 DEGREES FAHR.), OIL QUENCHED AND TEMPERED AT 620 DEGREES CENT. (1148 DEGREES FAHR.). MAGNIFICATION, 200x.

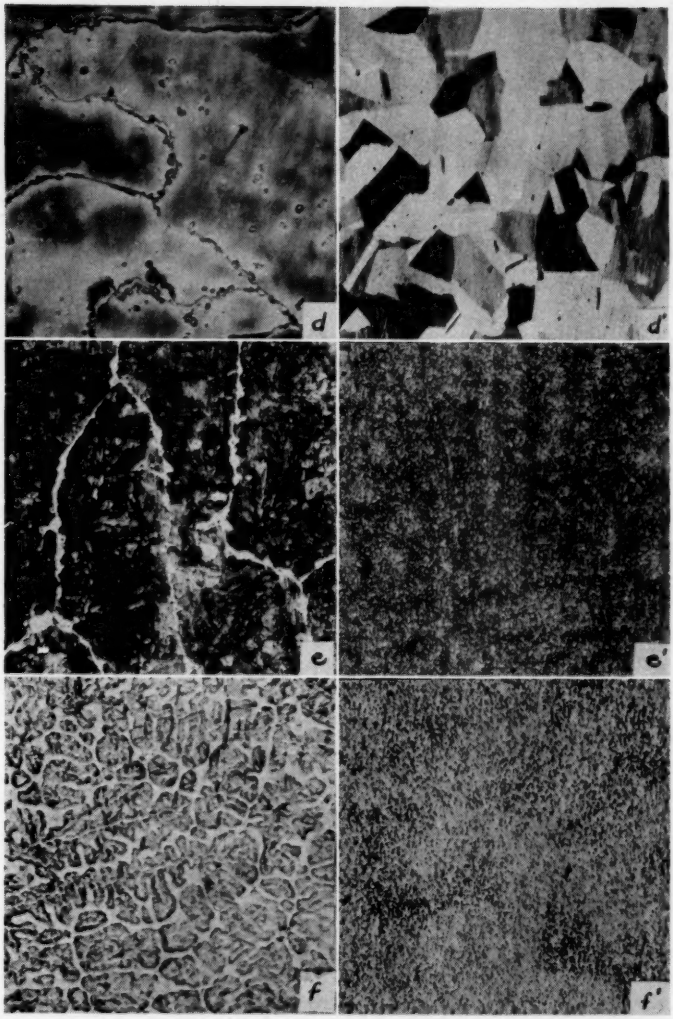



FIG. 13—(d), AUSTENITIC MANGANESE STEEL, CONTAINING 12.0 PER CENT MANGANESE, IN THE AS CAST CONDITION. MAGNIFICATION 50x; ($d^1$), SAME STEEL WATER QUENCHED FROM 1000 DEGREES CENT. (1832 DEGREES FAHR.). MAGNIFICATION, 200x; (e), ALLOY CAST STEEL CONTAINING 0.35 PER CENT CARBON, 1.60 PER CENT NICKEL, 0.70 PER CENT CHROMIUM AND 0.70 PER CENT MANGANESE IN THE AS CAST CONDITION. MAGNIFICATION, 50x; ($e^1$), SAME STEEL ANNEALED, REHEATED TO 850 DEGREES CENT. (1562 DEGREES FAHR.) OIL QUENCHED AND FINALLY TEMPERED AT 650 DEGREES CENT. (1202 DEGREES FAHR.). MAGNIFICATION, 50x; (f), STAINLESS STEEL CONTAINING 14.0 PER CENT CHROMIUM IN THE AS CAST CONDITION. MAGNIFICATION 50x; ($f^1$), SAME STEEL ANNEALED, REHEATED TO 960 DEGREES CENT. (1760 DEGREES FAHR.), OIL QUENCHED AND TEMPERED AT 750 DEGREES CENT. (1382 DEGREES FAHR.). MAGNIFICATION, 200x.

duces the ultimate shapes most likely best to serve his purposes and looks to the foundry to make the best job it can of the case. The result generally is good. It should, however, be borne in mind that a higher factor of safety is advisedly applied in the case of castings than in the case of forgings. The occasional unsoundness or the hidden defect must not unduly prejudice the working parts.

64. As regards specifications for castings, it might be observed that the intrinsic properties of cast and properly heat-treated steel are excellent, but frequently as regards the cast-on test pieces, it must be pointed out that there is difficulty in arranging the local feeding of the steel to produce perfect soundness and thus bring out the intrinsic values of the material in the test figures. This is a universally appreciated difficulty with castings which cannot be too much emphasized. Everything points to the wisdom of complete confidence and interchange of ideas between the designer, the engineer and the steel founder. As regards the design, the manufacture and the final testing, much is to be gained by such intimate collaboration.

## CONCLUSION

65. In conclusion, the author would like to record his appreciation and thanks to Mr. C. W. D. Townsend, general manager, Firth-Brown Foundries, Scunthorpe, Lincs, England, and to Mr. G. Stanfield, M. Eng., B.Sc., and his other colleagues at the Brown-Firth Research Laboratories, for the assistance rendered in the investigations described.

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## DISCUSSION

*In the absence of the author, this paper was presented by H. Spence Thomas, Vice President of the Iron and Steel Institute, (British) and official representative of that organization at the Fifth International Foundry Congress.*

*The chairman of the steel session before which this paper was presented was John Howe Hall, Taylor-Wharton Iron & Steel Co., High Bridge, N. J.*

F. A. MELMOTH[1], (*Submitted in Written Form*): Dr. Hatfield is well known in this country, for a number of very good reasons, any one of which would justify careful attention to a contribution by him dealing with steel castings. From a personal viewpoint, an added keenness of interest on my part is to be expected, as my last business connection in

[1] Detroit Steel Casting Company, Detroit, Mich.

England before my emigration to this country was that of foundry manager with the firm with which Dr. Hatfield has been so long connected.

The present paper is an interesting description of the methods obtaining in Great Britain in a foundry of this type. The remark made in paragraph 2 referring to the demands upon English foundries, and their differences when compared with American foundries, would have been more literally correct a few years ago; but I think that most of my colleagues who are responsible for steel casting production in this country today, would doubt whether any greater university of demand could be made upon foundries than is today the common occurence in this country. This diversity is not only one of design of casting and size, or a question of oddment orders, but one of widely differing materials, calling for diverse methods of handling, a wider and more varied knowledge of steelmaking, and a grasp of suitable heat treatment for the many and varied types of steel involved. In other words, it is true today to say that this type of demand has called for equal skill and resort on the part of American steel foundrymen. Except in very rare instances, they can not longer settle down to the rapid repetitive production of one or a limited number of castings of a definite type and size. This fact adds to the interest of the present paper, as it is written from the viewpoint of the foundry handling difficult castings of a type not usually called for in large numbers.

In these days of competition, particularly from fabricated welded products, it is consoling to see in paragraph 4 that Dr. Hatfield considers the art of making steel castings to have reached a very high standard, and it is even more interesting to note his emphasis on the matter of designing, if a casting is to be produced economically and satisfactorily for the purpose intended.

We will all heartily agree with the need for continued and extended research in steel founding, and, as an expression of personal opinion only, I should like to say that I consider research in steel founding to be traveling at a much faster pace in this country than has ever been the case before, either here or in Great Britain. The steel foundry can hardly be said to be the recipient of very much research interest on the part of our more prominent and highly developed metallurgists. Many years ago, in a paper given in Great Britain, I referred to the steel castings industry as the "Cinderella" of the steel trade. I feel sure that each year since that time has seen a definite tendency towards the realization that the steel foundry offers immense possibilities of research, and that the successful accomplishment of these investigations and their absorption into practice can be followed by the establishment of steel castings as a much more widely used metal product. The examples shown by Dr. Hatfield, in his illustrations, are very well chosen indeed, to show the effectiveness of proper methods of production, and are representative of quite a wide scope of applicability.

It will be realized that the paper is not controversial in character. It does not raise points either in molding practice or furnace practice which could become the subject of the keen arguments to which we have been accustomed in many of our meetings. It has, however, great value, in that it enables us to make comparisons, both of method and results obtained, to compare our miscrostructures with those shown as typical for

certain definite compositions and heat treatments, and therefore to widen our knowledge of this most intricate branch of the steel industry.

Dr. Hatfield has passed over the manufacture of the steel with one very short paragraph, and I believe it would add very greatly to the interest of his paper if in replying to the discussion he would give his considering opinion on the influence of process on the results obtained with the complicated type of casting he uses as illustrations in his paper. I know that in the foundry with which he is connected, several differing steelmaking methods are available—acid open hearth, basic electric, and acid converter. Unfortunately, acid electric practice is not common in England, and this phase of the comparison therefore can not be dealt with. In this country, we have arrived, or are arriving, at fairly definite opinions on the influence of steelmaking process on the manufacture of certain types of castings, and, as a means of comparison, such information from Dr. Hatfield would be of very current interest.

P. E. MCKINNEY,[2] (*Submitted in Written Form*): The author has presented in a very clear and concise manner many problems concerning production of castings which are similar in Great Britain and this country.

In his opening statements the author refers to the diversity of requirements confronting the individual foundry in Great Britain, which might infer that such conditions do not exist in America. While a very large output of American steel foundries is of a specialty nature involving repeat production of similar castings to serve one or more specific branches of industry, we have in this country a very large number of so-called jobbing foundries whose activities cover not only a wide variety of designs and weight of castings for various industries but also cover production of steel in a variety of compositions.

The author is to be complimented on the very thorough survey which he presents on the basic features of steel foundry practice and the excellent examples he presents of typical casting operations. The author's discussion of the various factors entering into the successful production of steel castings involving sand requirements, properties of cores, molding problems, use of chills and feeder heads, is in general accord with American views.

In this country, on account of the wide geographic distribution of steel foundries, the selection of sands must oftentimes be controlled by economic considerations involving freight rates, which precludes the same degree of standardization as is possible in Europe. However, the American foundryman has made an excellent accounting in the intelligent use of these sands through quite extensive research on sand control which has been carried out for a number of years under the auspices of the American Foundrymen's Association supported very generally by the foundry industry.

We cannot too strongly emphasize the importance of the fullest cooperation between designer and foundryman and heartily concur in the author's remarks on this subject. As pointed out by the author, the necessary departure from the ideal cast form of an ingot necessitates the resorting in the fullest measure to all the ingenuity and skill of the foundryman in producing sound castings. Therefore, design which reconciles the

[2] Bethlehem Steel Company, Bethlehem, Pa.

requirements of the designing engineer with the inherent properties of solidifying metal, will invariably tend to the production of the soundest finished casting members.

The author has made no reference to welding of steel castings and it is unfortunate that in a great deal of our discussions of steel castings, the question of welding is lightly passed over. We are referring not only to welding which is occasionally necessary and desirable for salvaging castings which develop imperfections, often indirectly the result of impractical design requirements, but also to such welding as is required in assembly of the castings either by welding castings together or by the erection of castings into other structures by welding.

In a great deal of light construction in America, fusion welding is being resorted to as an efficient method for assembly in lieu of other methods such as bolting, riveting or keying. Welded joints in such cases are given a very definite efficiency rating and the welding operations are surrounded with very exacting safeguards to assure their general soundness.

With the increasing necessity to utilize welding in connection with the use of steel castings, a great deal of study is being given in America to the welding properties of cast steel—special grades of material being selected which are weldable without serious injury through the development of cracks, warpage, distortion, etc.

A great deal of prejudice has existed in the general subject of welding castings, which is not warranted and with the research which is being carried out by various private and public interests in America, it is felt that within the course of the next few years we will have some definite constructive contributions to offer on this subject.

Research activity in steel foundry practice in America has been very active, which can be shown by reference to publication over the last few years including the symposium on Steel Castings presented at the 1932 sessions of the American Foundrymen's Association.

Contributions such as presented at this session by Briggs and Gezelius on "Studies on Solidification and Contraction and Their Relation to the Formation of Hot Tears in Steel Castings", are typical of some of the types of research being conducted in America today.

R. A. BULL[3] (*Submitted in Written Form*): Dr. Hatfield's contribution is a very informative condensed treatise on steel founding as practiced in Great Britain. While the author's technical qualifications have long been recognized by all metallurgists in this country, it may be surprising to some persons to discover from a reading of the paper that Dr. Hatfield is familiar with the actual manufacture of steel castings as well as the production and expert evaluation of wrought metal products. No experienced foundryman who has studied the paper would doubt that the author understands many factors which are involved in the production of sound steel castings, but which cannot be appreciated by competent metallurgists who have not had direct contact with the molders' art.

Dr. Hatfield's contribution contains descriptions of the manufacture of certain intricate castings, thus presenting useful suggestions for the

[3] Consultant on Steel Castings, Chicago.

members of the A.F.A. Collectively considered, the cast parts that have been described were such as to require a great deal of skill for their successful production. The detailed descriptions of the castings give evidence of the author's desire to make the paper helpful to his American colleagues.

In those portions of the paper which contain general observations, there are several comments that will be heartily endorsed in America. For example, Dr. Hatfield takes occasion to state tersely two important facts, as follows: "The designer always asks much of the foundryman. Sometimes he asks too much." Those who make miscellaneous steel castings for jobbing purposes realize the accuracy of these declarations prompted by experience. Happily, the factor of design is gradually becoming better appreciated by the consumers who regulate the shapes of cast steel parts required for industry. In the latter part of his paper, the author makes further reference to this design factor, in stating that the producer develops the ultimate shapes that are most likely best to serve the intended purposes, then looks to the foundry to make the best job of it can.

The opinion of the present writer is that too often the foundry tries to do the best possible job in producing an intricate casting without making adequate effort to secure a simplification of the design which would be helpful to all concerned. There are some foundrymen who assume too readily that the designer is arbitrarily fixed in his determination to have the casting made exactly as it was shown on the completed drawing. Experience gained in advocating design-revision is apt to demonstrate that the competent mechanical engineer generally concedes that the foundryman should know what he is talking about when he describes such relative inferiorities as are bound to be caused by certain abrupt changes of thickness, heavy members that are isolated so as to prevent adequate feeding, sharp corners at member-connections, etc. The present writer believes that a large proportion of the radical deficiencies in steel casting design are capable of being remedied, if the metallurgical phenomena incidental to the making of the piece are clearly explained by the foundryman to the customer. If and when we who are engaged in work related to steel founding become strongly addicted, as a class, to the practice of analyzing and trying to improve casting design before the pattern goes into the sand, the product of the steel foundry will be made more economically and will give a better account of itself in service.

While such points as these have frequently been made by American foundrymen, they have not been emphasized to the extent justified by the prevailing conditions. It is encouraging to note that an internationally recognized metallurgist who may be assumed to have more of a laboratory than a shop point of view, takes occasion to direct attention to this basic factor of sound casting production.

It is interesting to observe, particularly in view of some sweeping condemnations that have been voiced in America against the use of internal chills, that the author regards chills as advantageous in many cases, while wisely pointing out that their use calls for careful judgment. Since Dr. Hatfield's comments apply to chills without differentiating between internal and external application, one may assume that the author recognizes the occasional advisability of using internal as well as external chills. In this matter, as in many others, the foundryman frequently has to do the best

job he can under design conditions of extraordinary difficulty, where the task of developing a very high degree of resistance to severe combinations of mechanical stress throughout every portion of the casting is utterly impossible. Unfortunately, this is not appreciated by a good many designers. Incidentally it is to be remembered, and should be occasionally pointed out by the foundryman, that somewhat similar conditions obtain in respect to every cast or wrought part of any kind of industrial metal. The degree to which the properties inherent in any metal as delivered from the furnace may be secured in the completed cast, forged, or rolled device is contingent largely on dimensional conditions that are closely related to the required manufacturing processes.

The author has remarked that research into many of the recognized problems of steel founding is not easy, owing to the difficulty of experimenting as regards the physical chemistry of steel making and the determination of physical and mechanical values at the high temperatures involved. Nevertheless, as Dr. Hatfield asserts, the gradual accumulation of exact knowledge is changing the manufacture of steel castings from an art into a science. The interest that is being taken by experts who are theoretically well equipped for solving highly complicated problems should make practical steel foundrymen warmly appreciative of the assistance that has been given by men who, while having a clear understanding of metallurgical phenomena, have such a practical viewpoint as to appreciate many of the difficulties of applying theory to practice on the foundry floor.

The author concludes his paper with brief comments regarding test pieces. Many American foundrymen will endorse the statement that frequently test coupons attached to commercial castings are so placed as to prevent sufficient feeding for the development of the intrinsic value of the material. This fact can be easily demonstrated, and is related to another important fact which the author might have mentioned if he had felt it desirable to elaborate on this scheme. A test coupon attached to a commercial casting may be so placed as to be fed adequately and thereby develop satisfactory properties in the specimen, but with serious effect on the commercial casting itself, through the bleeding of the metal therein for the feeding of the test coupon. Conditions of this kind have been observed in striking manner in the experimental and commercial production of numerous castings. Such circumstances demonstrate the desirability in most cases of evaluating the material used for steel castings by means of a given standard, such as the coupon lying beneath an adequate feeding plate which will not, during contraction, draw metal from the member of a commercial casting. While this is well known to competent foundrymen, it is not always realized by casting buyers.

Undoubtedly American steel foundrymen will be grateful for the many useful comments and suggestive illustrations contained in Dr. Hatfield's paper.

CHAIRMAN HALL: Mr. McKinney brought up a point of very great interest in this country, and I presume elsewhere, when he spoke of the welding of steel castings, and, at the risk of calling attention to a subject that is somewhat trite, I would remind you of a rather interesting situation which prevails quite widely. Designers are more than willing to create structures in which they weld casting to casting and weld casting to

rolled metal and weld rolled metal to rolled metal, but, as some of our friends have pointed out, when you ask them to allow the welding of a seam in a steel casting which really does not demand the great strength that is necessary when a casting is welded to a casting, they say "Oh no, you may weld these two castings together but you cannot weld a crack in that casting, that is not to be thought of." We are making progress in that line, however.

E. H. BALLARD[4]: We wish to point out the necessity of giving consideration to composition of internal chills when used. Experience would indicate that, as far as possible, internal chills should be similar to or same as the composition of the casting being chilled. This also applies to the composition of welding electrodes. They must be such that deposited material will duplicate composition of casting being welded. This more particularly applies to alloy steels.

C. W. BRIGGS[5]: It seems strange to me that castings weighing 7½ tons and 13 tons should be cut up to show homogenity especially after they have received such extensive heat treatment. Such practice even in isolated cases is undoubtedly an expensive one. I believe that the technique of radiography, using either X-rays or gamma rays, has progressed to the point where foundrymen can understand and interpret radiographs as well as photographs of machine sectioned castings. Then again, where radiography is used the casting is saved for its intended application.

J. B. ALLEN[6]: Up to five years ago, and I believe the same thing holds good now, welding in England was looked upon generally as a heinous offense and it was quite impossible for any steel foundry to carry out welding without a written permit from the inspection authority concerned. Frankly, I feel that that attitude is very largely wrong, but it is the one that has held good for a number of years in England.

With that attitude, one felt that one was under a cloud in the steel foundry business because of this position on welding. Every one was inclined to look suspiciously at you if you even suggested welding. To some extent, that had a good effect, in that it focussed a tremendous amount of attention on details in design, and that, in turn, I think tended to produce better castings.

F. A. MELMOTH: I propose to correct one or two misconceptions. I have been over here long enough to know that the idea that the American founding industry is composed of a number of people who mechanically produce large numbers of castings from any one pattern, is quite incorrect. The actual difficulty of castings in this country is fully equal to the difficulties in Great Britain. I am not at all sure that a good many of my American friends present could not convince Dr. Hatfield that there are even more difficult castings produced in this country today than are normally produced in Great Britain. As an Englishman, my idea is that we should admit that right away, and base our premises on the facts, and not on the assumption that America is a mass production country, and

[4] General Foundry and Pattern Shop Supt., River Works, General Electric Co., West Lynn, Mass.

[5] U. S. Naval Research Laboratories, Washington, D. C.

[6] Stavely Coal and Iron Co., Ltd., Chesterfield, England.

that great skill is not necessary, but that the whole thing depends on perfect planning. It would interest Dr. Hatfield to see some of the tremendous castings made in this country, jobs which I know were not believed practicable in Great Britain. They are cast here every day and are perfectly successful.

The second general misconception is as to the progress of research on castings. We fully realize the need for research. Research is needed and is going on, and I want to say again, that research on steel castings as such is not only going ahead in this country faster but is going ahead on better lines than was the case in Great Britain up to five years ago. I sincerely hope that in that five years, since we have gone ahead so fast, one now can say that this statement is open to correction, but research in Great Britain purely on steel castings was not going ahead as fast as in America when I left. I will refer any one who doubts this to the published literature of foundry associations, the papers on sands, the papers on underlying causes of many steel foundry troubles, and I am quite sure that an unbiased judgment will prove my case.

Some fifteen years ago, I referred to the steel foundry industry in England as being the "Cinderella" of the steel trade. That term has been used by a good many people since, and I see no reason to say that we are yet quite out of that position. However, when one looks at the caliber of the papers in this particular convention, one has every reason to believe that we are fast getting out of it; we now get papers on such abstruse subjects as the Czechoslovakian one which Mr. Sims presented, and Mr. Sims own paper, which a few years ago would have been thought too high brow to present to an A.F.A. Steel Session, but we now know there is a real and practical connection between these abstruse subjects and the getting of a good casting. Please do not interpret these remarks into an assumption that I do not appreciate Dr. Hatfield's paper. I am saying this because I know him so well that I know he would prefer to get that side of the picture rather than mere acquiescence in anything he might say.

T. S. QUINN[7]: I am not prepared to discuss welding in any detail, although we have done a good deal of it at our plant. In reference to the remarks of the previous speakers, I think it is generally appreciated that the steel foundrymen are able to weld a low plain carbon steel with facility. That fact being recognized, permission is generally granted for reasonable repairs to castings of that composition, a fair assumption being that the work will be carried out properly by repairing the weld and not attempting to make welds in those places which are inaccessible and where a good weld cannot be made. I think the greater difficulty comes about when the service of castings demands a composition classified as alloy steel.

Those of us who have undertaken the manufacture of so-called low carbon steel have had it brought very forcibly to our attention that in dealing with materials of alloy composition, we cannot weld with the same ease and we cannot procure the same results unless exceptional precautions are taken with regard to subsequent treatment after welding. A very interesting slant on that is the development of alloy steel castings

[7] Lebanon Steel Catsing Co., Lebanon, Pa.

specifications while simultaneously there is taking place a tremendous development in the welding of plain carbon structural steel shapes. It would seem to me, therefore, that the steel foundry has an opportunity, by reason of the easier adaptability of plain carbon steel as against some of the other alloy steels in intricate castings, to advocate with confidence the use of plain carbon steel where weight is not the principal factor. We ourselves feel quite convinced that carbon steel not in excess of, say, 0.25 per cent carbon, can be welded with the same degree of security as many structural parts. In this connection, it should be borne in mind that an advantage frequently lies with the foundry industry, in that a suitable heat treatment can be applied to such welded castings, whereas with welded structural parts, suitable high temperature heat treatments cannot be applied.

C. E. SIMS[8]: I think Dr. Hatfield gave some rather timely admonitions in regard to the proper study and consideration of design of castings as well as design of molds.

He remarked in one part of his paper that it must never be forgotten that a steel casting is not a steel forging, and he goes on to explain the difference in the manufacture of the two products. It is true that a steel casting is not a steel forging, it is different, but for that a steel casting need make no apology. Millions of steel castings which have given long and satisfactory service have contained what Dr. Hatfield refers to as hidden defects. Most light castings of rangy design cannot be adequately shrunk and will contain some shrinkage down the center zone approximately midway between the surfaces. When the casting is considered as a whole this is the neutral zone of stress, but when a test bar is cut from such a casting it will likely be turned from the center metal. Consequently it compares unfavorably with a bar cut from a forging of similar design. This difference between castings and forgings should be frankly acknowledged and considered by both foundrymen and designers. This is not an admission of inferiority for a casting. I could cite a number of instances where castings have successfully replaced forgings that failed.

I was impressed, in the one example given of mold design, with the generous use of risers. I think we are inclined at times to be a bit niggardly in the use of risers, but what is probably more true is that, even when the matter of yield is utterly disregarded, too much consideration is given to problem of getting the riser off of the casting. Such is not the case with this turbine casting; the risers are properly connected to the casting so that they can adequately do the work for which they are designed.

CHAIRMAN HALL: Several of the speakers have called attention to the fact that in this paper, while very careful diagrams are given of how the turbine casing was headed, the other castings are shown merely in their perfect sections and we are left to wish we knew how they were gated and headed.

GERALD D. LINKE[9]: The Naval Gun Factory is making a very thorough investigation of the welding of steel castings. It has been found that

[8] American Steel Foundries, East Chicago, Ind.

[9] Lieutenant, U. S. Navy, Metallurgical and Testing Division, U. S. Navy Yard, Washington, D. C.

you can obtain as good results from the welding of castings as in the ordinary welding of steel plates. It might be stated that from our experience the welding of each different type of casting has its own particular problem. We endeavor to study these castings so as to obtain proper results. As an example, take a steel casting containing 1 per cent nickel, 0.25 per cent carbon and 0.75 per cent manganese. It has been found that if you weld this type of casting without proper preparation and precaution, cracking will result. Cracks do not show on the top of the weld, but will be at the bottom at the junction of the base metal and the weld and will extend out in a fan-like direction perpendicular to the axis of the weld. These cracks, in our opinion, are the result of contraction stresses that cause strains of rupturing magnitude in the small hardened plane of the casting parallel to the fusion zone.

Procedures have been developed that prevent the usual hardened areas and reduce the stress concentrations. This hardness may be prevented by either or both of two methods. The casting may be preheated and held at 400 to 500 degrees Fahr. during welding or the multiple layer method may be employed. The multiple layer method consists of covering the casting by a series of relatively short beads, each first layer bead being followed immediately by a second layer or covering bead. This sequence or the immediate application of the second layer prevents the heat affected zone of the casting from chilling rapidly and causing undue hardness. By avoiding the excessively hardened areas, the source of crack propagation is eliminated and similarly by reducing the cooling rate the severity of the cooling stresses are reduced. It is thus possible to obtain good welds with few if any cracks resulting. After welding the casting is then given its normal heat treatment.

In connection with the welding of castings and to assure that the welds are properly made, castings are X-rayed. If any of you gentlemen happened to be in the vicinity of the Naval Gun Factory we will be very glad to show you some of the results that we have obtained with this method of inspection. This X-ray equipment is of a portable type and can be taken to any particular place in our shops where X-ray examination of a casting is desired. This is very helpful because a casting does not have to be taken off the machine and then put back and set up after an X-ray examination is completed.

CHAIRMAN HALL: Mr. Melmoth spoke of the impression that seems to be prevalent so much abroad that in America we operate mostly production foundries, producing thousands of castings from a few patterns. I wonder if that is not partly our own fault? We are very proud of our production methods; the concerns which have cooperated with the foundries in putting in equipment are very proud of it, and when visiting foreign delegations come over here, they are very apt to study these production foundries at our invitation. Meanwhile, some foundrymen who run what has been referred to as jobbing foundries just carry the load and do not get visited nearly so often, and that is partly why that impression is carried back.

Dr. Hatfield's remarks that a casting is always a casting and must have a higher factor of safety than a forging on account of possible hidden defects, is of course, true. However, there have been for many years in

heavy forgings hidden defects of a type which possibly should not be referred to as defects, but as inherent weaknesses. The Joint Committee on the Effect of Phosphorus and Sulphur in Steel, which has worked so long in this country and, of which Major Bull and I have had the honor of being members, almost from its inception, ran into some very interesting data on the transverse and radial properties of 9 in. round forgings of 0.45 per cent carbon steel. There was one whole set of 9 in. rounds produced for the use and information of that committee which gave such poor properties in transverse and radial directions, that, somewhat to the disgust of the two foundrymen on the committee, it was decided that they were not representative and that a new set should be prepared. The results of the tests of the second set have recently been published and I commend them to the attention of foundrymen. A reasonable conclusion from those tests is that, as Giolitti pointed out in his book on the production of steel castings, a casting is often better than a forging when the part in question is to be stressed either radially or transversely, in spite of the well known fact that castings may contain hidden defects. The casting has the advantage that its physical properties are more or less equal in all directions, and that is far from being true of many heavy forgings.

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NOTE: In commenting on the discussion, a copy of which was sent to him for perusal, Dr. Hatfield said that he was very gratified with the direction that the discussion had taken and that he felt that there was little disagreement between the speakers and himself on the expressed views in regard to steel foundry work.

Dr. Hatfield stated that he might possibly have over-emphasized the difference in practice in England and America but that it was his impression that American foundries have much bigger lines to deal with than they have in England and that this results from the centralization of production which is more complete in America than in England.

He agreed that it might have been an added advantage if he had given full particulars of gates and runners instead of particularizing on the turbine casing but that it would have meant much more in the way of illustrations.

# Certainty of Results as the Basis for the Manufacture of High Test Gray Iron

By E. Piwowarsky,* Aachen, Germany.

**Abstract**

*The author states that the increase in properties of cast iron during the past 15 years has been due to the certainty of results made possible by increase in technical skill. He reviews some of his earlier work and, by new experiments, shows the influence of silicon, phosphorus, nickel, chromium, molybdenum, tungsten and copper, using hollow box-shaped castings for test pieces. It was found that the influence of silicon and phosphorus was unfavorable but that of nickel was favorable, when substituted for silicon. The influence of chromium, especially when used with nickel, was found to be favorable. In the absence of nickel, the hardening effect of chromium can be offset by not too high increases in silicon content. Molybdenum has an effect similar to that of nickel but does not have as favorable effect on hardness equalization as nickel. Tungsten and copper have a mildly favorable influence or may be neutral. The author describes a new shear test and results of this test show the influence of the various elements named. A simple relation between the different properties of gray iron is developed and critically evaluated. Finally the author compares results obtained from single separately cast test bars with those found in test bars cut from the hollow box-shaped test castings.*

1. The extraordinarily great progress which has been made in all the industrial countries in the last 10 or 15 years in the production of mechanically high test gray iron consisted not only in increasing the actual strength but even more in increasing the certainty of results. Cast iron with strength of 37,000 lbs. per sq. in. and thereabouts and even cast iron with a completely pearlitic matrix, was not entirely unknown 30 years ago; still the specifications of strength had to be considerably lower then because the

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Note: This is the German Exchange Paper which was presented by the author at a session on Cast Iron at the Fifth International Foundry Congress held in Philadelphia in conjunction with the 1934 Convention of the A.F.A.

certainty of results, that is, the technical skill in reaching definite values not only of the physical and chemical properties depending on the metallic matrix, but also of the mechanical properties depending mostly on the graphite formation, was insufficient.

2. There was, moreover, the exceedingly great dependence of the properties of cast iron on the thickness of the castings, which characterized the cast iron of pre-war times. For this last property, there has been used in Germany for several years the expression: "Wandstarken-Empfindlichkeit des Gusseisens," which means "The Sensitivity of the Structure of Gray Iron to the Thickness of the Cross-Section of the Castings." Some believed this to be a fine designation.

3. The author believes that it is not wise for the gray iron industry to use this expression, considering the growing competition among various casting alloys. The builder or engineer not sufficiently previously trained in metallurgy or the technology of materials, may come to the conclusion that only gray iron shows this property of sensitivity to the thickness of the cross-section, whereas all cast alloys, whether ferrous or nonferrous, show this influence.[1]

4. The fact that the graphite formation in gray iron makes more difficult a later homogeneizing or equalizing of the difference in properties determined by the casting conditions in different sections of a casting varying in thickness, can not justify keeping the expression "Wall thickness sensitivity of gray iron" any longer, because the disadvantage of iron castings of pre-war times has been counteracted and minimized by collaboration between science and practice in the case of gray iron to a degree such as is common to all cast alloys. Neither the steel nor the nonferrous founder speaks of the "sensitivity of steel castings or bronze castings to section." It should be enough, therefore, for the gray iron founder also to accept as natural and in accordance with the fundamental laws of crystallization, the influence on the structure and other properties of any metallic material exercised by the thickness of the casting, that is, by the rate of cooling, and not to give the impression that it is an exclusive property of cast iron.

[1] For aluminum alloys with 10 per cent zinc and 2 per cent copper, according to the work of W. Claus and Ju-Sze-Tsai (*Giesserei*, 1928, p. 342), the strength varies from 18 to 10 kg. per sq. mm. (26,000 to 14,220 lb. per sq. in.) as the section of the casting increases from 5 to about 90 mm. (0.2 to 3.5 in.).

For the alloy 92 per cent aluminum and 8 per cent copper, widely used in Germany, H. W. Gillett (Circ. Bur. Standards No. 346, p. 153, 1927) states that the strength decreases from 14 to 9.5 kg. per sq. mm. (19,900 to 13,500 lb. per sq. in.) as the section increases from 10 to about 26 mm. (0.4 to 1.0 in.).

5. Since the year 1920, the certainty of results as a basis of the production of gray iron of desired qualities, has been greatly improved through the use of special cast-iron diagrams which make possible the adjustment of the carbon and silicon contents to the thickness of the cross-section of the casting by consideration of the desired structure (Maurer, Greiner & Klingenstein, Thrasher, Portevin) or the strength attainable, and materially increased the certainty with which the quality of gray iron can be kept close to the optimum (Coyle).

6. Naturally, the expert will take into consideration the fact that the boundary lines of the structural and strength fields in the cast iron diagrams vary more or less with differences in melting and casting conditions. So, for example, iron melted in the cupola, air furnace, electric furnace, or high frequency furnace will have an increased tendency towards carbide formation in the order named (cupola least, and so on) and will therefore need increasing percentages of graphitizing elements (silicon, nickel, aluminum, and titanium). Sometimes there is a peculiar pig iron in the mixture, which tends to render the cast iron harder or softer, and therefore alters the fields in the cast iron diagram. Superheating the liquid iron, soaking the melt at a moderate temperature, deoxidizing the cast iron thoroughly by melting it under a slag low in ferrous and manganous oxide and other means, increase the tendency of the cast iron toward carbide formation.

## BETTER CONTROL NOW POSSIBLE

7. The successful melting of larger proportions of steel scrap in the mixture (Emmel, Coyle) as well as in general a better control of the oxidizing and carburizing conditions in the cupola furnace; heat treatment of the liquid iron in the realm of pig iron production, producing a finer form of graphite and improvements in the matrix, as carried out in Germany for example in the production of "Migra-Iron"[2] (the name is abbreviated from micrographite) at the Friedrich-Wilhelms-Huette[3]; and numerous other methods (also such things as sand control, etc.), have resulted, in Germany and in most other industrial countries in the last 10 or 15 years, in the development of a high test cast iron which, in corresponding measure, also exhibits an independence of its qualities with respect to the variations of the section of the castings.

[2] STAHL und EISEN, p. 664, 1932. German Patent No. 552,838.
[3] DIE GIESSEREI, v. 19, p. 121, 1932.

8. Early in 1926, the author[4] showed that with increasing superheat of the liquid iron, the cast iron not only formed increasingly finer graphite, but also became increasingly more independent of changes in the cooling and solidification rates as far as graphite formation is concerned, and therefore of changes in section.

9. The author has shown[5] that the controlling tendency since 1925 towards raising the specifications for the strength of gray cast iron is really attributable to the increased certainty of results, as well as to the systematic influencing of the graphite-formation (which mostly determines the strength), and to a lesser degree, to the refining of the metal matrix, which is clearly characterized by the Brinell hardness. The possibility of influencing graphite formation favorably, that is, removing the notch effect of the graphite enclosures, showed the technically practicable and economically feasible way to improve systematically the metallic matrix, through strengthening heat treatments, or through the addition of certain alloying elements.

## STRUCTURE IS IMPORTANT

10. Fig. 1 shows schematically, in approximately the quantitative proportions, the relation between the form and amount of graphite on one hand, and the structure of the metallic matrix on the other. We assume, as is well known, that ordinary low-carbon gray iron with too fine a graphite formation, so that the primary solid solution envelops it in an interlocking network, can really be a disadvantage.[6]

11. For gray iron, which undergoes no later heat treatment, such as annealing or strengthening, it is naturally important that the castings have from the start the desired structure, because for so many properties (hardness, wear, machinability, heat and growth resistance, magnetic and electrical properties) the structure of the metallic base is of importance. In addition, the amount of shrinkage on casting depends on the structure of the metal, and if the structural difference between various sections is decreased, the amount of casting strains, and therefore the danger of cracks, are markedly lessened.

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[4] GIESSEREI-ZEITUNG, v. 23, pp. 379-414, 1926. Also *"Hochwertiger Grauguss,"* Julius Springer, Berlin, 1929, p. 83.

[5] Piwowarsky, E., *"Hochwertiger Grauguss,"* (*Higher Strength Gray Cast Iron*), published by Julius Springer, Berlin, 1929, Fig. 252, p. 284.

[6] BULLETIN, Association Technique de Fonderie, v. 8, p. 96, 1934.

12. From the foregoing observations, it appears that founders must try to produce a gray iron that will be as nearly as possible independent of changes in cooling rate, and therefore of changes in section, not only with regard to graphite formation but also with regard to the structural characteristics of the metal matrix. However, the problem of the designer remains today, just as formerly, to design the castings of any cast alloy in such a way as

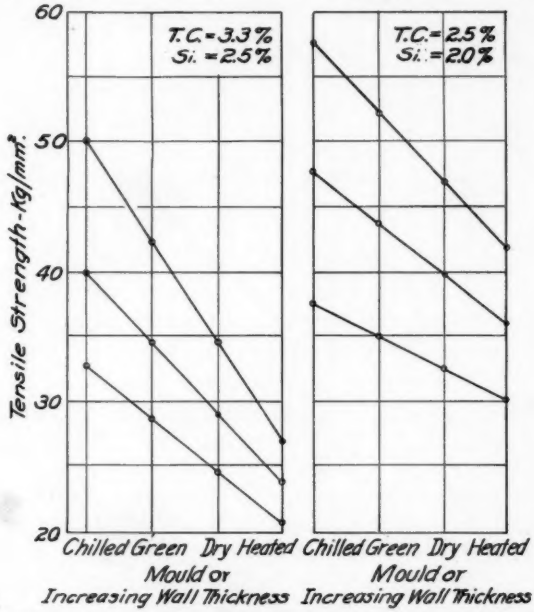


FIG. 1—INFLUENCE OF THE FORM AND AMOUNT OF GRAPHITE ON THE TEMPERING QUALITY OF CAST IRON.

to present the least possible variations in the thickness of their cross-sections.

13. In a thesis by the author published[7] in 1931 based on melting experiments in an oil-fired crucible furnace, the influence of different constituent elements on the Brinell hardness of separately cast test bars of 10, 20, 40 and 100 mm. (25/64 — $\frac{25}{32}$ — 1⅝ — 4 in.) diameter was determined. This was in agreement with know results, especially American research,[8] that silicon and phosphorus have a very unfavorable, and nickel an extremely favorable,

[7] DIE GIESSEREI, v. 18, p. 533, 1930.
[8] Especially those of the International Nickel Co., New York.

influence. Unfortunately, in this first experiment in the laboratory, because of the very low carbon concentration (around 2.6 per cent) and the small amounts melted (about 22 lbs.), the carbide content was too high, especially in the thinner sections, in the experiment with increasing silicon, so that the hardness curve was very unusual, although of course it showed the general tendency.[9]

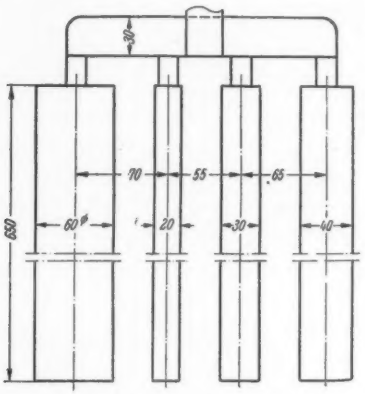


FIG. 2—CASTINGS FOR TESTING THE INFLUENCE OF SECTION ON PROPERTIES OF CAST IRON. DIMENSIONS GIVEN IN MILLIMETERS.

14. Therefore the experiment was repeated and the determination of the tensile strength included. This time metal was melted in a 400 KW luminous-arc electric furnace of 1100 lbs. (500 kg.) capacity and mixtures corresponded to those used in practical foundry operation.[10] The material was again cast horizontally in round bars (Fig. 2) in green sand. Unfortunately, the carbide content of the melt partly was still too high in this test. Nevertheless, in relation to each other, the figures obtained corresponded to the expected curve.[11]

15. The unfavorable influence of high silicon and phosphorus, as well as the favorable influence of nickel even in the presence of higher phosphorus contents could be confirmed. Especially convincing are the results as illustrated by a diagram suggested by

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[9] Piwowarsky, E. and Sohnchen, E., DIE GIESSEREI, 1931, p. 533.

[10] Published in ZEITSCHRIFT DES VER. DEUTSCHER INGENIEURE, v. 77, p. 463, 1933.

[11] Piwowarsky, E. and Sohnchen, E., ZEITSCHRIFT DES VER. DEUTSCHER INGENIEURE, 1933, p. 463.

P. A. Heller,[12] according to which the differences in strength values between the 20 mm. (25/32 in. round) bar and the heavier sections (Fig. 3), are expressed as percentages and plotted, taking the values for the 20 mm. (25/32 in.) bar, as 100 per cent.

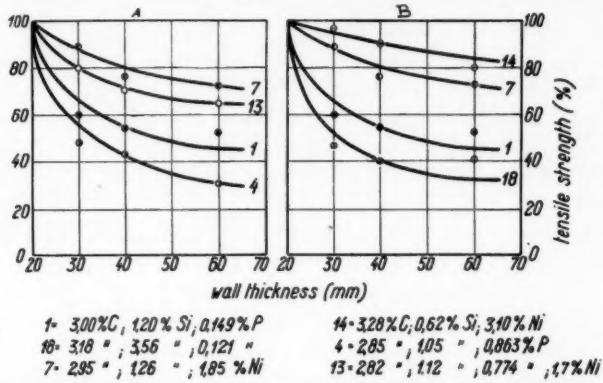


FIG. 3—RIGHT—PERCENTAGE REDUCTION OF TENSILE STRENGTH WITH SECTION, FOR DIFFERENT SILICON AND NICKEL CONTENTS. LEFT—PERCENTAGE REDUCTION IN TENSILE STRENGTH WITH SECTION, WITH DIFFERENT SILICON, NICKEL, AND PHOSPHORUS CONTENTS.

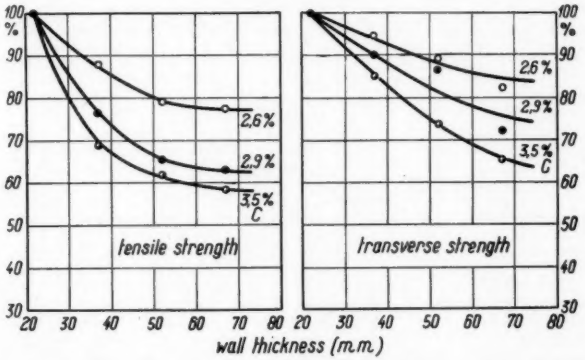


FIG. 4—INFLUENCE OF CARBON CONTENT ON THE TENSILE AND TRANSVERSE STRENGTHS OF GRAY IRON, AT DIFFERENT WALL THICKNESSES (A. KOCH AND E. PIWOWARSKY).

16. In Fig. 3A, one should notice how favorable are increasing substitutions of nickel for silicon. In regard to the other elements, it can be found in this last mentioned thesis, that aluminum is weakly harmful, and chromium and molybdenum have no ef-

[12] Heller, P. A., DIE GIESSEREI, v. 18, p. 237, 1931.

fect, except that chromium additions lessen the harmful effect of high silicon in the piece. In the experimental work to be mentioned later, molybdenum was found to give improved properties. Meanwhile, some experimental work done with A. Koch[13] shows the harmful effect of increased carbon on the tensile and transverse strength in heavier sections (Fig. 4).

17. Regarding silicon and carbon content, it was found and tallies with an evaluation carried out by P. A. Heller[14] of older data on hand, that castings from those melts which lie in the pearlitic portion of the cast iron diagram (for example, that of E. Mauer), will be least influenced in regard to their properties by variations in the thickness of their cross-section. Also, the low carbon irons of homogeneous structure (for example, made by the Emmel or Coyle process) are in accord with these results.

18. In consequence of the importance of the relation indicated here between certainty of results and the qualitative evaluation of gray iron, the author, together with E. Hugo and H. Nipper[15] made a series of 29 heats in an industrial cupola furnace, which were poured with the kind permission of the general directorate and the works management at the foundry of the Alexander Works in Remscheid (Germany). As shown on the heat log given in Table 1, it was intended to show again the influence of silicon and phosphorus on the strength properties of gray iron of a

**Table 1**

ANALYSIS OF HEATS* 1 TO 29 FROM WORK BY PIWOWARSKY, HUGO AND NIPPER

| Heat No. | Si. per cent. | P. per cent. | Ni. per cent. | Heat No. | Si. per cent. | Ni. per cent. | Cr. per cent. | Mo. per cent. | W. per cent. | Cu. per cent |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.25 | ..... | ..... | 15 | 2.30 | ..... | 0.30 | ..... | ..... | ..... |
| 2 | 2.00 | ..... | ..... | 16 | 2.75 | ..... | 0.75 | ..... | ..... | ..... |
| 3 | 3.50 | ..... | ..... | 17 | 3.25 | ..... | 1.25 | ..... | ..... | ..... |
| 4 | 2.00 | 0.4 | ..... | 18 | 2.00 | 1.50 | 0.75 | ..... | ..... | ..... |
| 5 | 2.00 | 0.8 | ..... | 19 | 1.63 | 2.25 | 0.75 | ..... | ..... | ..... |
| 6 | 2.00 | 1.2 | ..... | 20 | 1.25 | 3.00 | 0.75 | ..... | ..... | ..... |
| 7 | 2.00 | ..... | 1.0 | 21 | 2.00 | ..... | ..... | 0.2 | ..... | ..... |
| 8 | 2.00 | ..... | 2.0 | 22 | 2.00 | ..... | ..... | 0.5 | ..... | ..... |
| 9 | 2.00 | ..... | 3.0 | 23 | 2.00 | ..... | ..... | 1.0 | ..... | ..... |
| 10 | 1.50 | ..... | 2.0 | 24 | 2.00 | ..... | ..... | ..... | 0.5 | ..... |
| 11 | 1.00 | ..... | 3.0 | 25 | 2.00 | ..... | ..... | ..... | 1.0 | ..... |
| 12 | 1.50 | 0.4 | 2.0 | 26 | 2.00 | ..... | ..... | ..... | 2.0 | ..... |
| 13 | 1.50 | 0.8 | 2.0 | 27 | 2.00 | ..... | ..... | ..... | ..... | 0.5 |
| 14 | 1.50 | 1.2 | 2.0 | 28 | 2.00 | ..... | ..... | ..... | ..... | 1.5 |
| | | | | 29 | 2.00 | ..... | ..... | ..... | ..... | 2.5 |

*Analysis of the base heat was C, 3.3 per cent; Si, 1.5 per cent; Mn, 0.3 per cent; P, 0.2 per cent. Any additions or changes of these amounts are noted above.

[13] Koch, A., DIE GIESSEREI, v. 20, p. 1, 1933.
[14] Heller, P. A., DIE GIESSEREI, v. 18, p. 237, 1931 (same as 10).
[15] Thesis of E. Hugo, Aachen Technische Hochschule, 1934.

uniform and moderately high carbon content of about 3.3 per cent; also, the effect of nickel was to be examined on an iron with a uniformly low silicon content; moreover, the influence of chromium, molybdenum, tungsten, and copper was to be included. In melts 15 to 17, the silicon content was raised in equal proportion to the chromium content; in melts 18 to 20, with constant chromium, the silicon was increasingly replaced by nickel.

19. The cupola used had a diameter of 700 mm. (27.5 inches) and a tuyere zone with 4 tuyeres; it worked at 820 mm. (15.85 lbs. per sq. in.) blast pressure, and 90 cubic meters (3180 cubic feet) blast per minute. The charge was 250 kg. (550 lbs.) and the coke charge was 10 per cent, of 84 per cent carbon content. The mixture was:

32 Kg. ( 70.4 lbs.) ferrosilicon
20 " ( 44.0 " ) Luxemburg No. 3 pig iron
163 " (358.6 " ) malleable scrap
35 " ( 77.0 " ) wrought iron.

## METHODS OF ADDITION

20. The addition of alloy elements was made in the ladle. The tapping temperature of the iron was between 1340 and 1360 degrees Cent. (2445 and 2480 degrees Fahr.) 230 kg. (506 lbs.) were regularly tapped from the furnace, and were poured in plumbago washed dried sand molds in vertical position, to obtain the hollow block shown in Fig. 5, and four standard test bars 30 mm. diameter (1-3/16 in.) and 650 mm. (25-5/8 in.) long. With the small amount of steel used, about 14 per cent, and with a furnace charge for ordinary commercial castings, the iron poured was naturally not at all a high-strength material.[16] However, the relative value of the results was scarcely affected, especially since the charge and manner of melting guaranteed a great uniformity between the irons produced.

21. From the great wealth of material published on this subject, only the results of heats 1 to 11 and further, of heats 20, 27 and 29, will be treated more closely here. Table 4 shows also the most important results of the other experimental work. The sum-

[16]By a series of experiments at one of the largest foundries in Germany, in which the author participated, and where they are accustomed to produce very high strength iron, the strength of this high test cast iron was increased by nickel additions up to 2.3 per cent, from 8 to 10 kg. per sq. mm. (11,375 to 14,220 lb. per sq. in).

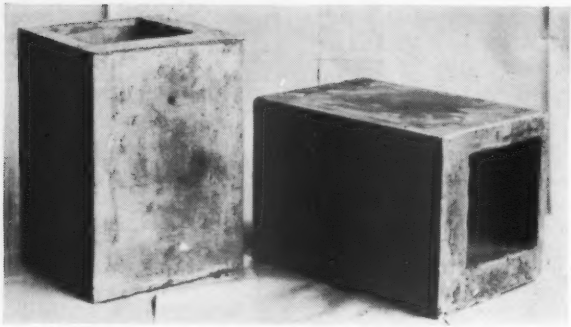

FIG. 5—CASTINGS USED FOR TEST SPECIMENS.

**Table 2**

CHEMICAL ANALYSIS OF IMPORTANT HEATS

| Heat No. | C per cent. | Si per cent. | Mn per cent. | P per cent. | S per cent. | Ni per cent. | Cr per cent. | Cu per cent. |
|---|---|---|---|---|---|---|---|---|
| 1 | 3.35 | 1.20 | 0.67 | 0.20 | 0.135 | ..... | ..... | ..... |
| 2 | 3.20 | 2.16 | 0.50 | 0.25 | 0.100 | ..... | ..... | ..... |
| 3 | 3.02 | 3.43 | 0.62 | 0.26 | 0.100 | ..... | ..... | ..... |
| 4 | 3.29 | 2.16 | 0.63 | 0.42 | 0.135 | ..... | ..... | ..... |
| 5 | 3.28 | 2.07 | 0.60 | 0.73 | 0.110 | ..... | ..... | ..... |
| 6 | 3.26 | 1.97 | 0.57 | 1.04 | 0.110 | ..... | ..... | ..... |
| 7 | 3.26 | 2.11 | 0.60 | 0.20 | 0.115 | 1.03 | ..... | ..... |
| 8 | 3.24 | 2.02 | 0.60 | 0.20 | 0.115 | 2.30 | ..... | ..... |
| 9 | 3.26 | 1.93 | 0.60 | 0.22 | 0.115 | 3.22 | ..... | ..... |
| 10 | 3.36 | 1.64 | 0.60 | 0.23 | 0.130 | 2.17 | ..... | ..... |
| 11 | 3.35 | 1.08 | 0.57 | 0.20 | 0.140 | 3.02 | ..... | ..... |
| 20 | 3.33 | 1.32 | 0.59 | 0.21 | 0.120 | 3.14 | 0.78 | ..... |
| 27 | 3.28 | 2.16 | 0.61 | 0.20 | 0.130 | ..... | ..... | 0.72 |
| 29 | 3.26 | 2.11 | 0.61 | 0.20 | 0.130 | ..... | ..... | 2.80 |

**Table 3**

PER CENT COMBINED CARBON IN THE FOUR SECTIONS 20, 40, 60, AND 80 MM.* THICK

| Heat No. | Total Carbon per cent. | Per cent Carbide | | | |
|---|---|---|---|---|---|
| | | 20 mm. | 40 mm. | 60 mm. | 80 mm. |
| 1 | 3.35 | 0.84 | 0.70 | 0.66 | 0.62 |
| 2 | 3.20 | 0.73 | 0.55 | 0.46 | 0.42 |
| 3 | 3.02 | 0.71 | 0.47 | 0.37 | 0.32 |
| 4 | 3.29 | 0.82 | 0.78 | 0.67 | 0.57 |
| 5 | 3.28 | 0.79 | 0.63 | 0.55 | 0.44 |
| 6 | 3.26 | 0.74 | 0.57 | 0.41 | 0.33 |
| 7 | 3.26 | 0.94 | 0.70 | 0.58 | 0.51 |
| 8 | 3.24 | 0.95 | 0.80 | 0.67 | 0.61 |
| 9 | 3.26 | 0.97 | 0.85 | 0.72 | 0.68 |
| 10 | 3.36 | 0.90 | 0.77 | 0.59 | 0.55 |
| 11 | 3.35 | 0.95 | 0.80 | 0.77 | 0.73 |
| 20 | 3.33 | 1.07 | 0.97 | 0.91 | 0.87 |
| 27 | 3.28 | 0.67 | 0.47 | 0.43 | 0.40 |
| 29 | 3.26 | 0.62 | 0.46 | 0.40 | 0.36 |

*20, 40, 60, 80 mm. equals ¾, 1½, 2$\frac{3}{4}$ and 3$\frac{5}{8}$ in.

**Table 4**

a—VALUES (INDICATION-VALUES) FOR THE DIFFERENT PROPERTIES*

| Heat No. | CC** | Strength Trans | Tens. | Shear | Bhn | Heat No. | CC** | Strength Trans. | Tens. | Shear | Bh |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.230 | 0.102 | 0.097 | 0.071 | 0.064 | 15 | 0.307 | 0.081 | 0.094 | 0.068 | 0.052 |
| 2 | 0.411 | 0.182 | 0.149 | 0.148 | 0.109 | 16 | 0.444 | 0.175 | 0.168 | 0.131 | 0.076 |
| 3 | 0.583 | 0.354 | 0.356 | 0.214 | 0.151 | 17 | 0.530 | 0.301 | 0.236 | 0.165 | 0.101 |
| 4 | 0.187 | 0.188 | 0.094 | 0.086 | 0.046 | 18 | 0.378 | 0.133 | 0.128 | 0.057 | 0.025 |
| 5 | 0.256 | 0.289 | 0.181 | 0.114 | 0.055 | 19 | 0.266 | 0.074 | 0.067 | 0.044 | 0.023 |
| 6 | 0.540 | 0.262 | 0.233 | 0.113 | 0.079 | 20 | 0.144 | 0.025 | 0.026 | 0.022 | 0.002 |
| 7 | 0.441 | 0.087 | 0.075 | 0.089 | 0.068 | 21 | 0.344 | 0.128 | 0.106 | 0.089 | 0.051 |
| 8 | 0.294 | 0.046 | 0.064 | 0.080 | 0.047 | 22 | 0.178 | 0.131 | 0.067 | 0.072 | 0.061 |
| 9 | 0.237 | 0.029 | 0.046 | 0.044 | 0.015 | 23 | 0.250 | 0.081 | 0.035 | 0.021 | 0.032 |
| 10 | 0.342 | 0.081 | 0.089 | 0.071 | 0.048 | 24 | 0.251 | 0.146 | 0.096 | 0.067 | 0.067 |
| 11 | 0.196 | 0.042 | 0.049 | 0.035 | 0.005 | 25 | 0.186 | 0.077 | 0.055 | 0.073 | 0.029 |
| | | | | | | 26 | 0.096 | 0.115 | 0.077 | 0.034 | 0.035 |
| 12 | 0.238 | 0.144 | 0.186 | 0.148 | 0.035 | 26B | 0.134 | 0.125 | 0.079 | 0.046 | 0.049 |
| 13 | 0.297 | 0.203 | 0.159 | 0.148 | 0.052 | | | | | | |
| 14 | 0.406 | 0.231 | 0.268 | 0.157 | 0.081 | 27 | 0.386 | 0.110 | 0.080 | 0.083 | 0.025 |
| 14B | 0.416 | 0.167 | 0.320 | 0.284 | 0.082 | 28 | 0.327 | 0.083 | 0.091 | 0.059 | 0.032 |
| | | | | | | 29 | 0.396 | 0.057 | 0.055 | 0.057 | 0.031 |

*a (the exponent which expresses the relation between the properties and the section of cast iron—see paragraph 43) is always negative.
**Combined Carbon in the form of carbides.

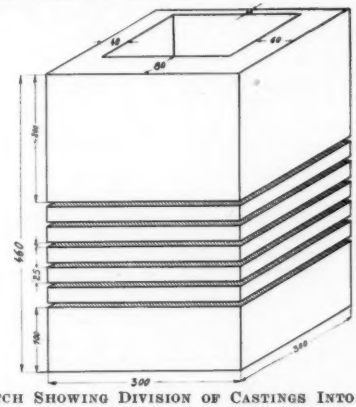


FIG. 6—SKETCH SHOWING DIVISION OF CASTINGS INTO TEST PIECES.

mary of these test heats is given in Table 2. One sees that the expected analyses generally were fairly well approached. The carbide content of these heats is shown in Table 3.

22. The division of the castings into test pieces is shown in Fig. 6. Five sections 25 mm. thick (1 in.) were sawed off across the casting. Taking into consideration the location of the three gates near the top of the casting, and the unfavorable influence on strength developed near them,[17] the first cut was made 100 mm. (4 in.) from the lower edge. The upper part, about 200 mm. (8 in.) in length, was kept as a reserve material.

[17] Wust, F., and Stuhlen, P., MITTEILUNGEN KAISER WILHELM INSTITUT FUR EISENFORSCHUNG, v. 4, p. 145, 1922. Zeyen, L., DIE GIESSEREI, v. 18, p. 178, 1931.

## How Test Pieces Were Cut

23. Figs. 7 and 8 show the sub-division of the various frames and the upper frame is shown in Fig. 7 *I*, the following in Fig. 8 *II*, and the third in Fig. 7 *III*, etc., to the lowest frame cut as in Fig. 7 *V*, to get the most uniform distribution of different test bars and to avoid getting similar test bars from the same part of the casting.

24. The heavy lines show the sawcuts dividing the 5 sections into 4 parts each, the thinner lines within these parts show the

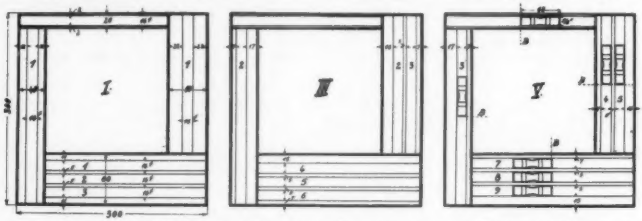

FIG. 7—LOCATION OF TEST BARS USED FOR TRANSVERSE AND TENSILE TESTS IN THE VARIOUS SECTIONS.

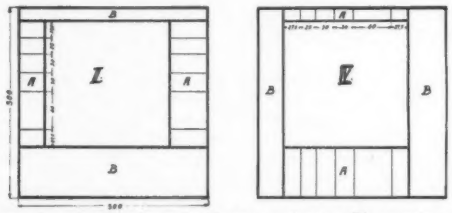

FIG. 8—LOCATION OF THE TEST PIECES USED FOR SHEAR, HARDNESS, AND STRUCTURE TESTS. LOCATION OF IMPACT TEST PIECES, IN THE SECTIONS ALSO IS SHOWN.

arrangement of the test pieces (Fig. 7 *I, III, V*). The transverse test bars have a thickness in the thinnest section of 16 mm. (5/8 in.) for a length of 160 mm. (6-5/16 in.) between the supports. Shown separately in section *V* are also the short tensile test bars which are omitted in both the others, on account of clearness. It is immaterial on which side of the point of fracture *B* of the parts the tensile test pieces are located because the transverse bars cut from parts varying in their thickness have corresponding characteristics.

25. The short tensile test bars are taken from the places shown. By doing so, the influence of adjoining section of the casting varying in thickness is minimized. The other halves of the transverse test bars of 20 mm. (25/32 in.) and 40 mm. (1-5/8 in.)

thickness, were used later for the preparation of tensile test bars, but no difference was found in the average tensile strength as compared to the test bars taken from the first half.

26. As shown in Fig. 7, the transverse test bars in the three sections are shifted in position, so that the total transverse section of the wall is subject to test and average values are secured. The number of test bars from each hollow block is given by the following summary:

| Wall Section in mm. | 20 | 40 | 60 | 80 | Altogether in 31 castings |
|---|---|---|---|---|---|
| Transverse, diam. 16 mm. | 3 | 3 | 5 | 9 | 620 |
| Tensile, short bars | 6 | 6 | 5 | 9 | 806 |

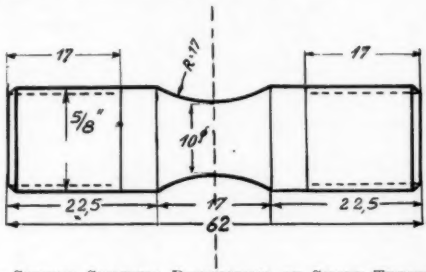


FIG. 9—SKETCH SHOWING DIMENSIONS OF SHORT TENSILE BAR.

27. The tensile bar (Fig. 9) was prepared according to the VDI[18] (Society of German Engineers) standards 15, sheets 12 and 14, without a parallel section. Two tensile test bars of 12 mm. (1/2 in.) diameter and 150 mm. (6 in.) length, were made from each of the broken halves of the standard transverse test bars of 30 mm. (1-3/16 in.) diameter and 600 mm. (23-5/8 in.) length. Their tests were in agreement with the test of the short tensile bars, which might have given too high values by lessening the elongation and reduction of area. This comparison was made only for the alloyed heats. A necking, and therefore a variation in strength values, did not occur with any of these short tensile bars.

28. Fig. 8 shows the division of the remaining section for the other tests. The portions marked *B* are being used for the preparation of endurance test bars, whose complete preparation is not yet finished, and whose research results will be published later. The portions marked *A* are so divided that test pieces are obtained for: (1) Fremont shear tests, (2) polishing and microscopic ex-

[18] DIE GIESSEREI, v. 17, pp. 758 and 903 (1930).

amination and hardness determinations, (3) the new shear test, proposed by the author, and (4) the punching-tests made according to Sipp-Rudeloff.[19] Fig. 10 shows the distribution of the specimens over the several wall thicknesses.

29. At each end of the casting is a waste piece, 27.5 mm. (1-5/64 in.) wide, that is not used for testing. This portion was discarded to avoid the zone which was influenced by the adjoining

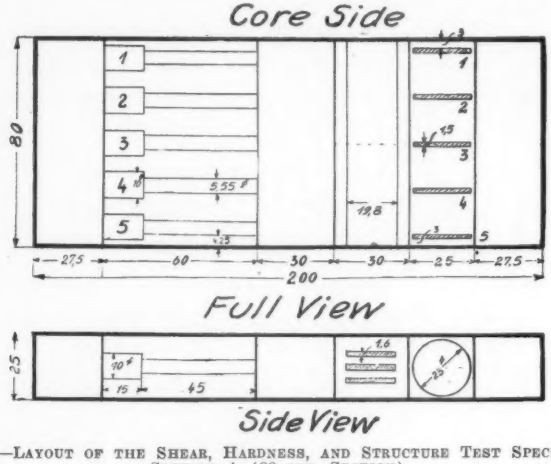


FIG. 10—LAYOUT OF THE SHEAR, HARDNESS, AND STRUCTURE TEST SPECIMENS IN SECTION A (80 MM. SECTION).

part in the original casting. On the left are the 60 mm. (2-3/8 in.) long cylindrical bars of 5.55 mm. (7/32 in.) diameter. Their heads were stamped, without hurting the bars, with the number and section. To get a picture of the strength curves of the whole cross-section, the bars were numbered consecutively from 1 to 4 or 5, as the case may be, beginning at the inside core of the casting and ending at the outside. The inside wall had originally been painted yellow for identification. The middle part, 30 mm. (1-3/16 in.) wide, was used for making metallographic specimens over the whole surface, and for Brinell hardness tests. The adjoining portion served for cutting out three plates 1.6 mm. (1/16 in.) thick, 19.8 mm. (25/32 in.) wide and as long as the original thickness of the casting permitted.

30. From these plates, beginning at the outside end, separate strips were stamped out later. The plates obtained from 20 mm.

[19] DIE GIESSEREI, v. 13, pp. 577 and 594 (1926) and v. 16, p. 218 (1929).

(25/32 in.) walls were sheared, not across, but lengthwise, and the width of the strips went over the whole thickness of the wall of the original casting. Thus the actual average strength could be obtained from the beginning. The same markings that were used on the Fremont test bars were put on the round punching plates 1.5 mm. (1/16 in.) thick and 23 mm. (29/32 in.) diameter, which were made from the portion of the casting adjacent to the right. The kind and number of test pieces from each section and its parts are shown in the following list:

| Section in mm. | 20 | 40 | 60 | 80 | Each casting | 31 Castings |
|---|---|---|---|---|---|---|
| No. of Piwowarsky test pieces.. | 3 | 3 | 3 | 3 | 12 | 372 |
| No. of Sipp-Rudeloff test pieces. | 2 | 3 | 4 | 5 | 14 | 434 |
| No. of Fremont test pieces..... | 2 | 3 | 4 | 5 | 14 | 434 |

## NUMBER OF TESTS POSSIBLE

31. While, with the Sipp-Rudeloff and Fremont test pieces only one test per plate or bar is possible, with the Piwowarsky method a number of test strips are sheared off from each test piece, the number depending on the thickness of the part. Therefore, many more single values are averaged, as is shown below:

| Section Part, | All-over Cross-section | From inside to outside | | | Each One | For 31 Heats |
|---|---|---|---|---|---|---|
| Thickness in mm. | 20 | 40 | 60 | 80 | | |
| Sum of strips sheared off one plate ..... | 5 | 4 | 7 | 9 | | |
| Sum of strips sheared off three plates ..... | 15 | 12 | 21 | 27 | 75 | 2325 |

32. A comparison of these figures (2325 values as against 434 values for Fremont and Sipp-Rudeloff) shows conclusively the advantage of the new test methods in obtaining a knowledge of the property changes across the section of a casting of any thickness.

33. This makes practicable the provision of numerous single values with the simplest preparation of the tests, and therefore the obtaining of the right average value.

34. As far as the testing of shear strength is concerned, the methods of Sipp-Rudeloff[20] and Fremont[21] are the most widely known. The stamping dies for the piercing tests designed by the

[20] Sipp-Rudeloff, DIE GIESSEREI, v. 13, pp. 577 and 594, 1926.
Sipp-Rudeloff, DIE GIESSEREI, v. 16, p. 218, 1929.
Sipp-Rudeloff, STAHL UND EISEN, v. 46, p. 1829, 1926.

[21] Fremont, REVUE DE METALLURGIE, Feb. 1928, p. 74.
L'USINE, Nov. 1921, p. 29.
FOUNDRY, 1930, pp. 94 and 101.

author are provided with three notches on their edges, equally spaced, about 1 mm. (1/32 in.) wide and 3.5 mm. (9/64 in.) deep. The other dimensions are given in Fig. 10. All test pieces were sawed or milled from the castings, then turned and polished as required.

35. Fig. 11 shows vertical sections through the special punch and die required by the new method. The steel cap (*a*) fits accurately and concentrically as far as possible over the round die block, (*b*). All pieces are hardened steel. A projection (*f*) fitting in a corresponding recess in the cap assures proper alignment of the punch and die. By means of the set screw (*e*) engaging slightly eccentrically in a conical depression in the die

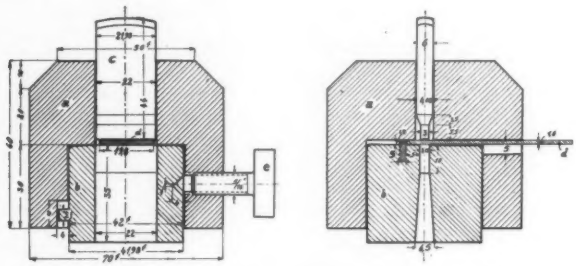

FIG. 11—MACHINE FOR TESTING SHEAR STRENGTH.

the latter is pressed tightly against the specimen and cap. The punch (*c*) is made of the finest tool steel and hardened, has its lower end narrowed and formed into a shear blade, and is guided firmly and truly through the high cap. The test piece (*d*) is advanced through a slot in the cap up to the stop (*g*). Any waste from the test piece must be removed after each punch operation, while the sheared off strips are passed through the die hole, which has a clearance of 0.15 mm. (0.006 in.). The tool was designed by the author's co-worker, E. Hugo, and built at the Alexander Works A. Co. A-G, Remscheid. The tensile and transverse testing machine of Losenhausen, suitably rebuilt, was used as a shear-punch-press. It was run by hand power and the proper speed was applied with greatest possible uniformity, the influence of which on the experimental results has been discussed by A. Portevin.[22]

[22] A. Portevin, REVUE DE METALLURGIE, March 1930, p. 140.

## DETERMINING HARDNESS AND GRAPHITE CONTENT

36. As already stated, the middle portions of the dissected sides of the original sections II and IV (Fig. 8), 30 mm. (1-3/16 in.) broad, were used for hardness testing and for the preparation of polished metallographic samples.

37. For hardness, the Brinell test machine was used, with the test specification at 750 Kg. pressure, 5 mm. ball, 30 seconds. Instead of the 10 mm. ball in general use, a 5 mm. ball was used, to keep the imprint as near as possible to the edge of the test piece; therefore, the distance from the middle of the imprint to the edge of the test piece could be made as small as from about 4 to 3.4 mm. (around 0.7 ball diameter).[23] According to the measurement-directions given by H. Esser and H. Cornelius,[24] the identification left by the ball was illuminated diagonally by two opposite lights, and its diameter measured in the plane through the lights and the indentation center.

38. In accordance to the thicknesses of the walls of 20, 40, 60 and 80 mm. (25/32, 1-5/8, 2-3/8 and 3-9/64 in.) respectively, 2, 4, 6 and 8 impressions were made in one line, and this was done on both sides of the test pieces, from the inner to the outer edge. In the 20-mm. (25/32 in.) section, an extra impression was made on the sides and between the two imprints each on top and bottom, all located in the same plane. The test pieces were finished perfectly, and polished fine.

39. The drill chips for samples for the determination of the amount of graphite were then taken by drilling through all 4 sides of the original hollow block close below the lowest sawed-off section. The sizes of the drills were selected so that each hole yielded approximately 10 grams, and each lot was used up completely in the determination. The drill holes of course went through the whole wall. These tests, the results of which are found in Table 1, were made by volumetric and gravimetric analysis.

40. Figs. 12 to 16 show clearly the results of the series of tests previously mentioned. The absolute values depending on the section and the attendant phenomena considered separately, were chosen with the view of comparison with earlier published work. The numbers on the curve at the left side of the figure

[23] STAHL UND EISEN, v. 52, p. 1272, 1932.
[24] H. Esser and H. Cornelius, STAHL UND EISEN, v. 52, p. 496, 1932.

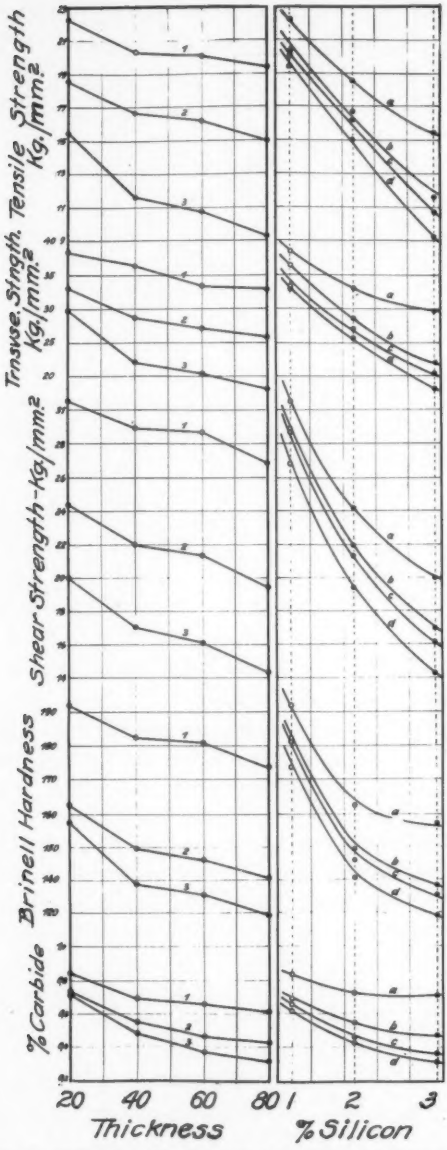


FIG. 12—EFFECT OF INCREASING SILICON AND SECTION ON PHYSICAL PROPERTIES OF CAST IRON (HEATS 1, 2, AND 3).

give the increasing section (20, 40, 60 and 80 mm.) (25/32, 1-5/8, 2-3/8, 3-9/64 in.). The unfavorable influence of silicon (Fig. 12) and phosphorus (Fig. 13) is shown again. The favorable influence of nickel is shown again, even in the series of heats 7 to 9 (Fig. 14) where no silicon reduction was made. It naturally

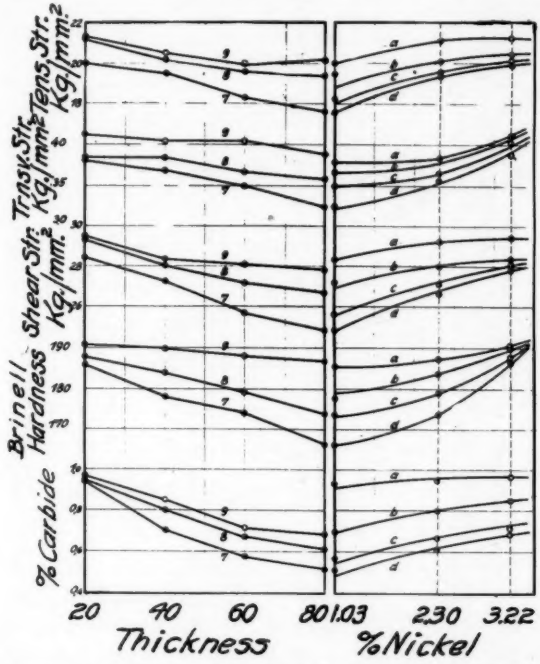


FIG. 13—EFFECT OF INCREASING PHOSPHORUS AND SECTION ON PHYSICAL PROPERTIES OF CAST IRON (HEATS 4, 5, AND 6).

appears more clearly and better defined in Fig. 15, where 1.00 per cent silicon was replaced by 2.00 per cent nickel. If, in addition, one compares also heat 2, which is similar but free of nickel, the picture is still more complete.

41. In the chromium-containing series of heats 18 to 20 (Fig. 16) the same influence of nickel is evident. The addition of molybdenum has a similar effect, only not so strong as that of nickel, while tungsten additions greatly increase strength, but hardly reduce the influence of section. What is said about tungsten also holds true for copper, which, however, is much less effective in

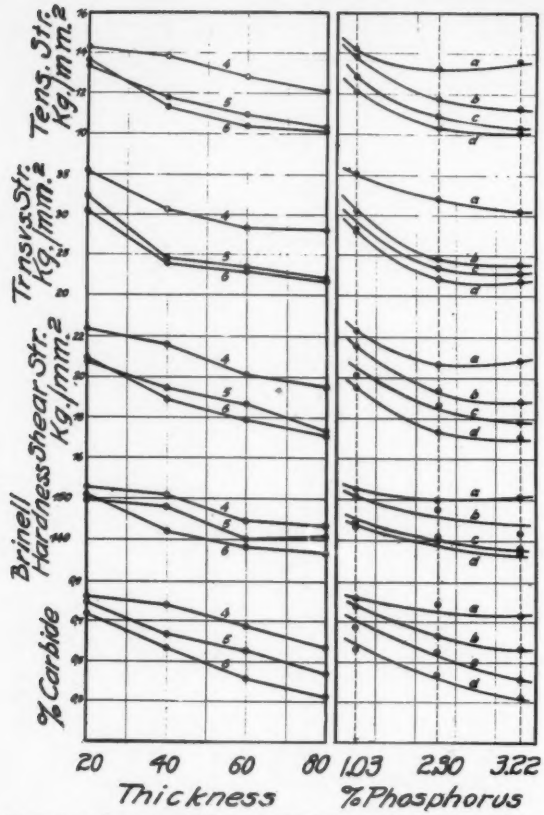


FIG. 14—EFFECT OF INCREASING NICKEL AND SECTION ON PHYSICAL PROPERTIES OF CAST IRON (HEATS 7, 8, AND 9).

increasing strength than tungsten. In Fig. 17 is shown the effect of silicon and nickel on the values for tensile strength and hardness, according to the work of P. A. Heller, expressed in percentage change, starting from a section of 20 mm. (25/32 in.). The last chosen representation in Fig. 17 is scarcely as convincing as the graphical representation of actual values, as in Figs. 12 to 16. The explanation is in agreement with H. Jungbluth and P. A. Heller,[25] that the influence of section is less with hollow or tubular castings than with separately cast round bars, where the ratio of surface to the volume affected is obviously much greater.

[25] Jungbluth, H., and Heller, P. A., ARCHIV FUR EISENHUTTENWESEN, v. 8, p. 75, 1934-1935.

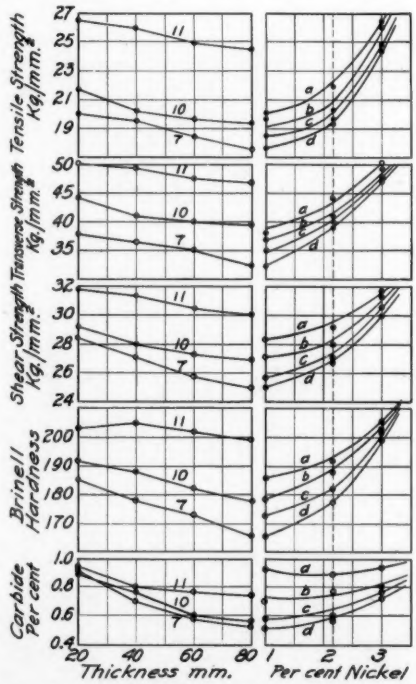


FIG. 15—EFFECT OF INCREASING NICKEL AND SECTION ON PHYSICAL PROPERTIES OF CAST IRON (HEATS 7, 10, AND 11).

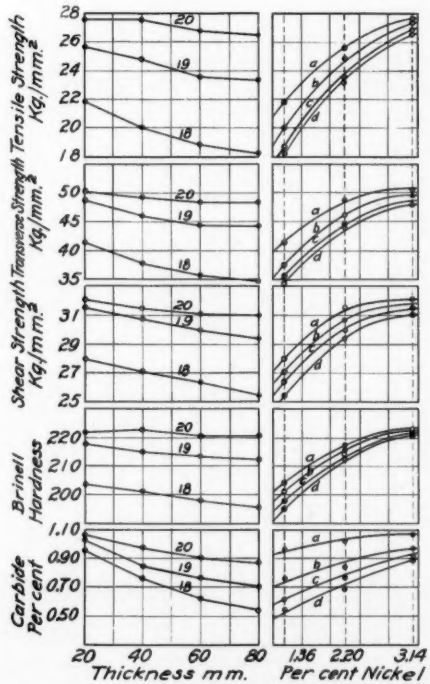


FIG. 16—EFFECT OF INCREASING NICKEL USED IN CONJUNCTION WITH CHROMIUM AND SECTION ON PHYSICAL PROPERTIES OF CAST IRON (HEATS 18, 19, AND 20).

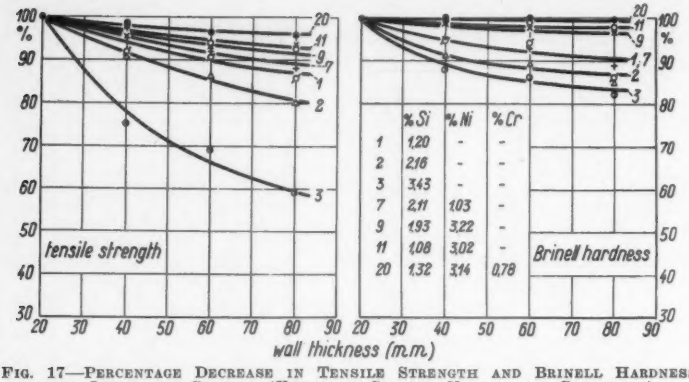


FIG. 17—PERCENTAGE DECREASE IN TENSILE STRENGTH AND BRINELL HARDNESS WITH INCREASING SECTION (EFFECT OF SILICON, NICKEL, AND CHROMIUM).

42. With reference to the relation between the properties of cast iron and the section ($d$), it has already been found by F. B. Coyle[26] for tensile strength ($\sigma_B$) and H. Jungbluth and P. A. Heller[27] for transverse strength ($\sigma'_B$) and hardness ($H$), to be of an exponential nature, that is for example, the equation for the transverse strength:

$$\frac{\sigma_{B_{d_1}}}{\sigma_{B_{d_2}}} = \frac{(d_1)^a}{(d_2)}$$

43. If the values obtained for the desired properties (that

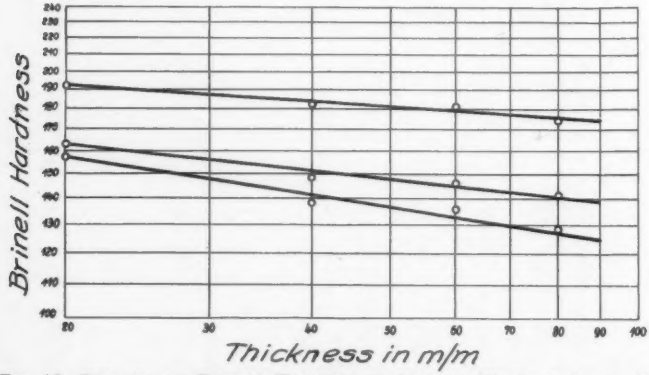


FIG. 18—RELATION OF BRINELL HARDNESS TO SECTION (HEATS 1, 2, AND 3), EXPRESSED LOGARITHMICALLY.

[26] Coyle, F. B., A.S.T.M. PROCEEDINGS, v. 29, pt. I, p. 118, 1929.
[27] Jungbluth and Heller, ARCHIV FUR EISENHUTTENWESEN, v. 8, p. 75, 1934-1935.

is tensile, transverse, and shear strength, Brinell hardness, and carbide content) are plotted in relation to the section in a logarithmic coordinate system, straight lines are obtained whose slopes toward the abscissa show the relation pictured as the influence of section. The relation between the lines may be stated, for Brinell hardness, by the equation:

$$\log B = a \log d + c$$

where $B$ is the Brinell hardness, $d$ is the section, $a$ and $c$ are

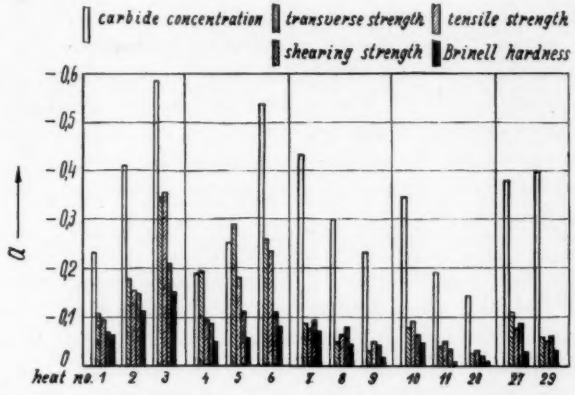


FIG. 19—QUALITY INDEX "a" FOR TRANSVERSE, TENSILE, AND SHEAR STRENGTH, CARBIDE CONCENTRATION, AND BRINELL HARDNESS.

constants; $a$ is the slope of the straight line and is always negative, $c$ is the Brinell hardness for section 1 ($d$ = 10 mm. or 25/64 in.).

44. Fig. 18 shows the relation between Brinell hardness and section for heats 1 to 3 with increasing silicon content. The $a$-values were also obtained for the other important properties investigated in this study; they are summarized in Table 4 and shown graphically in Fig. 19. The order of magnitude of the $a$-values vary

| | | | | | |
|---|---|---|---|---|---|
| For tensile strength | between | 0.026 | and | 0.36 | |
| For transverse trength | " | 0.025 | " | 0.35 | |
| For shear strength, Piw. | " | 0.020 | " | 0.28 | (average) |
| For Brinell hardness | " | 0.002 | " | 0.15 | |
| For carbide content | " | 0.09 | " | 0.60 | |

45. H. Jungbluth found in his research work with round bars cast separately considerably higher values for a, viz:

| | | | | | |
|---|---|---|---|---|---|
| $a$ | between | 0.20 | and | 0.70 | for tensile strength |
| $a$ | " | 0.20 | " | 0.45 | " transverse strength |
| $a$ | " | 0.14 | " | 0.42 | " Brinell hardness |

46. The variations in $a$-values, which in general must be smaller for hollow or box shaped castings than for the round bars of the earlier methods, are still quite sufficient to clarify the influence of various alloying elements. The high silicon and high phosphorus heats showed the highest $a$-values, the nickel-alloyed heats, especially those heats containing nickel together with chromium, and likewise the molybdenum heat have the lowest a-values. The $a$-values for the carbide content and Brinell hardness of the nickel and nickel-chromium heats are, however, not even approximately approached by the molybdenum-alloyed heats, a proof of the extraordinarily favorable influence of nickel as an equalizer of hardness.

### EFFECT OF CHROMIUM

47. As far as the effect of chromium alone is concerned, the unfavorable values of heats 15 to 17 do not show in any way a harmful influence of chromium. They rather show that in silicon-rich heats with over 2 per cent silicon, the hardening influence of chromium is already counterbalanced even by smaller contents of silicon than would correspond to a substitution in the ratio of 1:1, for silicon-poor heats and also for chill or hard iron castings, this statement about the 1:1 ratio holds good. When increasing silicon over 1.5 per cent, and especially over 2.0 per cent, the substitution ratio "silicon:chromium" must be dropped gradually to 0.5:1, if the benefit of a pearlitic matrix is to be retained. The smaller efficiency of tungsten in diminishing the influence of section likewise comes to light in the a-values, the same being true of copper.

48. An attempt to define the relations between the $a$-values for the different strength properties, gave such widely scattered results, that reproductions of the results could not be considered. Instead of those relations, Table 5, in which are given for all the sections studied the values for the most important properties of the heats, according to Table 2, was supplemented by Meyersberg's transverse test values

$$Z_f = F - \sigma'_B$$

($Z_f$ is the specific deflection, $f$ is the total deflection, $\sigma'_B$ is the

transverse strength) likewise their reciprocal values, known as Thum's Quotient $\sigma^1_B \cdot f$, which characterizes the graphite formation. H. Jungbluth and P. A. Heller[28] pointed out Meyerberg's

**Table 5**

AVERAGE VALUES AND STRENGTH PROPERTIES AND THEIR RELATIONS TO ONE ANOTHER AND VALUES OF THE ISOFLEX CONSTANTS

| Heat No. | Section mm. | Transverse | Deflection | Tensile Strength | Brinell Hardness | —Shear Strength— | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | $\sigma'_B$ | $f$ | $\sigma_B$ | $H$ | $S_z$ | $S_e$ | $S_s$ | $\frac{\sigma'_B}{f}$ | $\frac{f}{\sigma_B}$ | $\sigma'_B : H$ |
| 1 | 20 | 38.50 | 9.35 | 22.20 | 192 | 30.50 | 30.04 | 28.89 | 4.12 | 24.29 | 1: 8.65 |
| | 40 | 36.50 | 9.17 | 20.47 | 182 | 28.89 | 28.27 | 27.84 | 3.98 | 25.11 | 1: 8.89 |
| | 60 | 33.53 | 8.22 | 20.23 | 181 | 28.74 | 27.73 | 26.31 | 4.08 | 24.52 | 1: 8.95 |
| | 80 | 33.23 | 8.78 | 19.40 | 174 | 26.85 | 25.70 | 24.03 | 3.79 | 26.43 | 1: 8.97 |
| 2 | 20 | 33.00 | 8.21 | 18.64 | 163 | 24.35 | 23.23 | 22.11 | 4.02 | 24.88 | 1: 8.74 |
| | 40 | 28.52 | 7.83 | 16.78 | 149 | 22.00 | 21.32 | 19.99 | 3.64 | 27.45 | 1: 8.88 |
| | 60 | 27.00 | 7.66 | 16.28 | 146 | 21.32 | 20.51 | 19.53 | 3.53 | 28.37 | 1: 8.97 |
| | 80 | 25.75 | 7.99 | 15.00 | 141 | 19.40 | 18.48 | 16.96 | 3.22 | 31.04 | 1: 9.40 |
| 3 | 20 | 29.85 | 8.93 | 15.52 | 157 | 20.00 | 19.64 | 18.04 | 3.34 | 29.92 | 1:10.12 |
| | 40 | 21.95 | 8.10 | 11.60 | 138 | 17.00 | 16.79 | 15.33 | 2.93 | 36.90 | 1:11.90 |
| | 60 | 20.20 | 7.20 | 10.82 | 136 | 16.10 | 15.79 | 13.83 | 2.81 | 35.64 | 1:12.57 |
| | 80 | 18.15 | 7.05 | 9.28 | 129 | 14.31 | 13.94 | 12.46 | 2.57 | 38.84 | 1:13.90 |
| 4 | 20 | 35.50 | 11.48 | 14.30 | 153 | 22.40 | 21.97 | 19.65 | 3.09 | 32.34 | 1:10.70 |
| | 40 | 30.65 | 9.75 | 13.84 | 151 | 21.59 | 21.31 | 18 95 | 3.14 | 31.81 | 1:10.91 |
| | 60 | 28.27 | 9.00 | 12.80 | 145 | 20.10 | 19.84 | 17.41 | 3.14 | 31.83 | 1:11.33 |
| | 80 | 28.15 | 9.37 | 12.13 | 143 | 19.50 | 19.02 | 16.71 | 3.00 | 33.28 | 1:11.79 |
| 5 | 20 | 32.30 | 10.88 | 13.30 | 150 | 20.70 | 20.58 | 18.11 | 2.97 | 33.68 | 1:11.28 |
| | 40 | 24.50 | 9.10 | 11.80 | 148 | 19.45 | 19.23 | 17.35 | 2.69 | 37.14 | 1:12.54 |
| | 60 | 23.48 | 8.95 | 10.93 | 140 | 18.70 | 18.48 | 15.96 | 2.62 | 38.12 | 1:12.81 |
| | 80 | 22.20 | 8.81 | 10.30 | 141 | 17.30 | 17.09 | 14.83 | 2.52 | 39.68 | 1:13.69 |
| 6 | 20 | 30.30 | 9.68 | 13.60 | 151 | 20.20 | 19.86 | 17.47 | 3.13 | 31.95 | 1:11.10 |
| | 40 | 24.00 | 8.00 | 11.30 | 142 | 18.90 | 18.48 | 16.37 | 3.00 | 33.34 | 1:12.57 |
| | 60 | 23.00 | 7.88 | 10.31 | 138 | 17.94 | 17.53 | 15.16 | 2.92 | 34.26 | 1:13.39 |
| | 80 | 21.75 | 7.50 | 10.03 | 137 | 17.10 | 17.20 | 13.49 | 2.90 | 34.48 | 1:13.66 |
| 7 | 20 | 38.03 | 10.70 | 20.00 | 186 | 28.44 | 28.06 | 26.66 | 3.55 | 28.00 | 1: 8.30 |
| | 40 | 36.90 | 10.35 | 19.60 | 178 | 27.20 | 27.01 | 25.24 | 3.57 | 28.06 | 1: 9.08 |
| | 60 | 35.00 | 10.63 | 18.36 | 174 | 25.70 | 25.33 | 23.50 | 3.29 | 30.37 | 1: 9.48 |
| | 80 | 32.50 | 10.24 | 17.60 | 166 | 24.92 | 24.38 | 22.58 | 3.17 | 31.51 | 1: 9.43 |
| 9 | 20 | 41.36 | 11.97 | 21.43 | 191 | 29.57 | 29.79 | 28.07 | 3.46 | 28.93 | 1: 8.91 |
| | 40 | 40.62 | 12.05 | 20.50 | 190 | 28.42 | 28.22 | 26.19 | 3.37 | 29.66 | 1: 9.26 |
| | 60 | 40.50 | 12.04 | 19.95 | 188 | 28.13 | 27.93 | 25.14 | 3.36 | 29.72 | 1: 9.42 |
| | 80 | 38.70 | 11.46 | 20.20 | 187 | 27.87 | 26.66 | 24.64 | 3.38 | 29.60 | 1: 9.26 |
| 11 | 20 | 50.08 | 14.19 | 26.52 | 203 | 31.82 | 31.29 | 29.17 | 3.53 | 28.36 | 1: 7.65 |
| | 40 | 49.58 | 14.27 | 25.92 | 205 | 31.36 | 31.10 | 29.03 | 3.47 | 28.78 | 1: 7.91 |
| | 60 | 47.73 | 14.33 | 24.75 | 202 | 30.51 | 30.03 | 27.12 | 3.33 | 30.02 | 1: 8.16 |
| | 80 | 47.00 | 13.96 | 24.30 | 199 | 30.00 | 29.29 | 26.47 | 3.37 | 29.70 | 1: 8.19 |
| 20 | 20 | 50.05 | 11.20 | 27.70 | 222 | 32.00 | 30.90 | 29.95 | 4.47 | 22.38 | 1: 8.01 |
| | 40 | 49.30 | 11.00 | 27.48 | 223 | 31.50 | 30.13 | 28.75 | 4.48 | 22.31 | 1: 8.11 |
| | 60 | 48.21 | 10.40 | 26.89 | 221 | 31.12 | 29.50 | 27.92 | 4.42 | 22.61 | 1: 8.22 |
| | 80 | 48.18 | 10.83 | 26.62 | 221 | 30.98 | 29.40 | 27.82 | 4.45 | 22.48 | 1: 8.30 |
| 27 | 20 | 32.00 | 10.83 | 17.28 | 168 | 24.80 | 23.93 | 21.16 | 2.96 | 33.84 | 1: 9.72 |
| | 40 | 30.50 | 10.30 | 16.77 | 165 | 23.24 | 22.04 | 19.69 | 2.96 | 33.77 | 1: 9.84 |
| | 60 | 28.00 | 10.08 | 15.56 | 166 | 22.84 | 21.11 | 18.24 | 2.78 | 36.00 | 1:10.67 |
| | 80 | 27.00 | 9.55 | 15.32 | 162 | 22.30 | 20.30 | 18.30 | 2.83 | 35.37 | 1:10.57 |
| 29 | 20 | 38.14 | 11.18 | 20.60 | 190 | 27.60 | 27.20 | 25.60 | 3.41 | 29.31 | 1 :9.22 |
| | 40 | 36.90 | 10.88 | 20.00 | 185 | 26.44 | 26.24 | 24.50 | 3.39 | 29.49 | 1: 9.25 |
| | 60 | 36.90 | 10.85 | 19.65 | 184 | 26.00 | 25.70 | 23.90 | 3.40 | 29.40 | 1: 9.36 |
| | 80 | 33.90 | 10.43 | 18.78 | 181 | 25.35 | 25.00 | 22.90 | 3.25 | 30.77 | 1: 9.64 |

[28] H. Jungbluth and P. A. Heller, ARCHIV FUR EISENHUTTENWESEN, v. 5, p. 519, 1931-1932.

bending values as especially qualified, for a true picture of influence of section, on account of less scattering of test results, than for instance the bending strength or the deflection ($f$) when each is scattered alone by itself. While with increasing section $Z_f$ increases, the value of $\sigma'_B:f$ decreases correspondingly with more and coarser graphite formation.

49. Noteworthy are the high values of $\sigma'_B:f$ for the nickel-chromium heats 18 to 20; they prove as well as the extremely low values for $Z_f$ their well-defined insensitiveness to changes of section and therefore to cooling rates. Finally, the relation of $\sigma'_B:H$ (transverse strength : hardness) according to the work of A. Gimmy[29] also is shown in Table 5. This ratio has a real justification, because it reflects the influence of the graphite formation and also at the same time, the influence of the matrix. Increasing values of $\sigma_B$:H are always welcome as an indication that the strength of the matrix is up in an increasing measure.

## THE SIGNIFICANCE OF SHEAR STRENGTH

50. It is valuable to know not only the average strength in the separate sections, but also the strength in the different parts of each section, from outside to center, to distinguish the effect of section. Numerous such experiments have been made in the case of hardness. Most of them are the work of American investigators, who have shown in this way the influence of nickel on hardness. The relation between tensile strength and hardness naturally varies very widely, since these two values bring into play basically different properties of cast iron. This is where the shear strength seems to be suitable to depict correctly the properties of cast iron, obviously being influenced as much by the graphite formation as by the type of metallic matrix. For different kinds of ordinary cast iron, there is a very strong variation, for instance, in the relation between the shear strength and the tensile strength or Brinell hardness (up to 25 per cent) while with high test cast iron, the relation is more uniform.

51. In order to discover exactly the changes in properties over a known section, Fremont's or Sipp-Rudeloff's tests are less suitable, for the reasons stated at the beginning of this work; they are too complex and too expensive; but the method originated by the author permits, by the determination of $S_z$, a simple and therefore cheap determination of property changes. While

[29] A. Gimmy, DIE GIESSEREI, v. 20, pp. 235 and 280, 1933.

for instance, according to Fig. 10, only 5 tests for $S_s$ (Fremont) and $S_e$ (Sipp-Rudeloff) were made on the 80 mm. (3-9/64 in.) section, nine strips were stamped out of one plate for $S_z$, and since for each test three plates were used for an accurate determination of the average value, there are 27 separate values on hand for the determination $S_z$.

52. Fig. 20 shows the experimental results for $S_z$ on the 40, 60 and 80 mm. (1-5/8, 2-3/8, 3-9/64 in.) sections of heats 1 to 3 (silicon series) and for the nickel or nickel-chromium alloyed heats

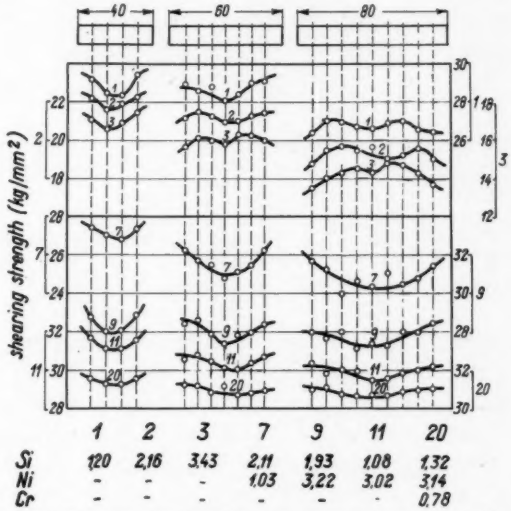


FIG. 20—CURVES SHOWING SHEAR STRENGTH IN SECTIONS OF 40, 60, AND 80 MM. THICKNESS.

7, 9, 11 and 20. Because of their noteworthy course, the curves for the copper-containing heats 27 and 29 were also included in Fig. 20. The shear tests was executed from the inner edge to the outer edge of the test piece. The peculiar shape of the curves for heats 1 to 3 can be traced to the fact that the zone next to the surface shows a ferritic structure, as frequently happens with castings made in dried and blackened sand molds.[30]

53. Dennecke and Meierling[31] have pointed to the carbide dissociation in the outer stratum of castings. F. Roll[32] confirms this phenomenon, and tries to explain it by a catalytic effect of

[30] DIE GIESSEREI, v. 19, p. 1, 1932.
[31] Dennecke and Meierling, GIESSEREI-ZEITUNG, p. 180, 1927.
[32] Roll, F., DIE GIESSEREI, v. 20, p. 233, 1933.

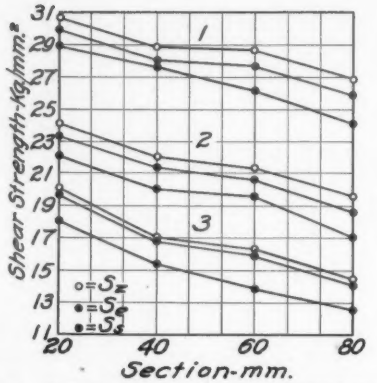


FIG. 21—COMPARISON OF SHEAR STRENGTH AS FOUND BY THE THREE DIFFERENT METHODS (SILICON SERIES).

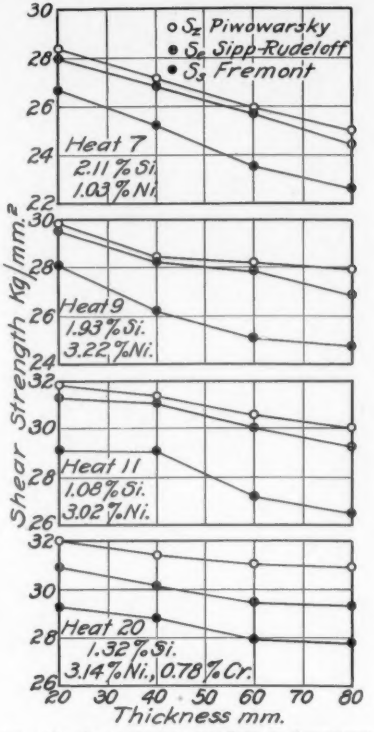


FIG. 22—COMPARISON OF SHEAR STRENGTH AS FOUND BY THE THREE DIFFERENT METHODS (NICKEL SERIES).

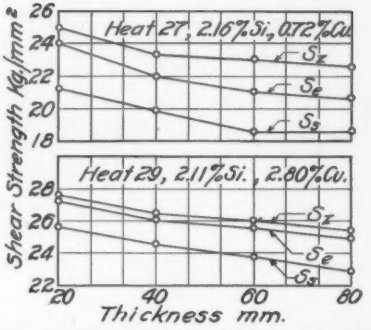


FIG. 23—INFLUENCE OF SECTION ON THE SHEAR STRENGTH OF CAST IRON WITH 3.3 PER CENT CARBON AND DIFFERENT COPPER CONTENTS.

the gas caused by the mold blacking. Probably this phenomenon is related to certain silicon contents. It is obvious, that without this effect the difference between $S_z$ edge and $S_z$ center in heats 1 to 3 would be appreciably greater. The curves for heats 7, 9 and 11 and 20 show again in a convincing way the favorable influence of nickel and nickel-chromium, and thus confirms the statements of American investigators.

54. It is noteworthy that the heats containing copper have such great variations in strength values within a given section, although with regard to the average strength values of different sections, only a slight influence of copper can be detected.

## CORRELATES VALUES

55. Figs. 21 to 23 show the values of $S_z$ as compared with $S_s$ and $S_e$ for the heats of the silicon, nickel and copper series. The $S_z$ values are the highest and, moreover, show slightly less scattering. It is important, moreover, that the agreement between the $S_z$ and $S_e$ (Sipp-Rudeloff) values is appreciably better than that between $S_z$ and $S_s$ (Fremont) values (see also Fig. 24). This may perhaps be traced to the all-too-small cross-section of the Fremont test-piece, that with $F = 23.75$ sq. mm. (0.037 sq. in.) is considerably under $F$ for $S_z$ (63.5 sq. mm. [0.098 sq. in.]) or for $S_e$ (85 sq. mm. [0.131 sq. in.]).

56. In Fig. 25 is shown the percentage change in shear strength values of $S_z$, $S_e$, and $S_s$ for the 80 mm. (3-9/64 in.) section, taking the average value of the 20 mm. (25/32 in.) section as equal to 100 per cent. The picture is plain and confirms earlier work.

57. For the relation between $S_z$ and the other properties, it was found:

Tensile strength $\sigma_B = 0.7\ S_z$

Transverse strength $\sigma'_B = 1.39\ S_z$

58. These equations are applicable in cases where the straight locus of the relation $\sigma'_B : S_z$ or $\sigma_B : S_z$ is drawn through the origin, as is usually done in the literature. The above formulae, however, do not conform accurately to the values. Truer values are found by the equations for the transverse strength:

$\sigma' = (S_z - 7) \times 1.98$ for high test alloyed iron

$\sigma'_B = (S_z - 4) \times 1.61$ for unalloyed irons, and especially high-phosphorus heats with ordinary qualities.

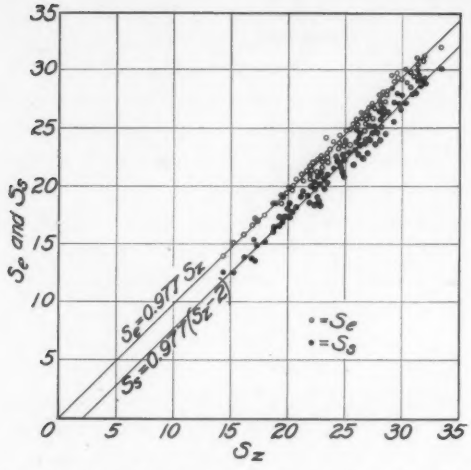


FIG. 24—SHEAR STRENGTH $S_z$ IN RELATION TO $S_e$ AND $S_s$

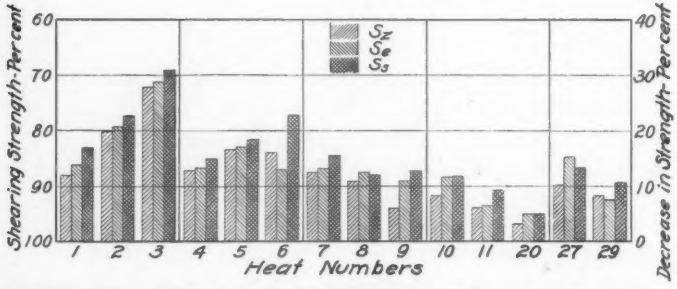


FIG. 25—PERCENTAGE DECREASE IN SHEAR STRENGTH, IN $S_z$, $S_e$, AND $S_s$, IN THE 80 MM. THICK SPECIMENS, AS COMPARED WITH THE VALUES FOR THE 20 MM. SECTION AS 100 PER CENT.

59. We know from this that the relation $\sigma_B' : S_z$ increases with increasing quality of the material. For the tensile strength similar facts were found, as follows:

$$\sigma_B = (S_z - 7) \times 1.08 \text{ for high test alloyed irons}$$

$$\sigma_B = (S_z - 8) \times 1.04 \text{ for the less good kinds}$$

Also for the tensile strength, the ratio $\sigma_B : S_z$ increases strongly with increasing strength.

60. For the relation between $S_z$ and the hardness $H$, for the alloyed high test irons, there was found an average value of

$H = 6.61 S_z$ but the straight locus best fitted the observed points correspond to

$$H - 40 = 5.16\ S_z$$

The poorer heats have higher proportions for $H : S_z$.

61. Finally, in Table 6 are shown the values for transverse strength of the individually cast round bars in the "as cast" and machined state, compared with those of the 16 mm. (5/8 in.) round bar cut from the 20 mm. (25/64 in.) section. While the "as cast" tested bars were cast to 30 mm. (1-3/16 in.) diameter, the other bars were cast with 34 mm. (1-11/32 in.) diameter and then machined down to 30 mm. (1-3/16 in.) diameter. The values were in very good agreement, as the cooling conditions of the 20 mm. (25/32 in.) thick wall-section approximate closely the cooling conditions of the 30 mm. (1-3/16 in.) separately cast round bars. Also Table 6 goes to show that the 30 mm. diameter machined bars generally have a higher strength. If the bars are machined too deep, so that the fine-grained, fine-graphite surface region is entirely removed, exactly opposite results are obtained. The many contradictions found in the literature support this explanation offered.

**Table 6**

COMPARISON OF THE TRANSVERSE STRENGTH AND DEFLECTION OF SEPARATELY CAST TEST BARS AND THOSE TAKEN FROM A 20 MM. SECTION*

| Heat No. | Transverse Strength | | | Deflection | | |
|---|---|---|---|---|---|---|
| | Test-bar 20 mm. dia. x 160 mm. | Standard-bar 30 mm. dia. 600 mm. long | | Test-bar 20 mm. dia. x 160 mm. | Standard-bar 30 mm. dia. 600 mm. long | |
| | | Machined | As cast | | Machined | As cast |
| 1 | 38.50 | ..... | ..... | 9.35 | ..... | ..... |
| 2 | 33.00 | ..... | ..... | 8.21 | ..... | ..... |
| 3 | 29.85 | ..... | ..... | 8.93 | ..... | ..... |
| 4 | 35.50 | 36.05 | 35.10 | 11.48 | 11.47 | 10.85 |
| 5 | 32.30 | 30.82 | 28.80 | 10.88 | 10.45 | 9.70 |
| 6 | 30.30 | 29.78 | 27.85 | 9.68 | 9.48 | 6.80 |
| 7 | 38.03 | 38.17 | 37.80 | 10.70 | 10.75 | 10.35 |
| 8 | 38.53 | 39.06 | 39.22 | 11.04 | 11.17 | 10.85 |
| 9 | 41.36 | 40.88 | 40.06 | 11.97 | 11.87 | 11.30 |
| 10 | 44.00 | 45.22 | 43.15 | 10.96 | 11.20 | 9.85 |
| 11 | 50.08 | 51.43 | 48.20 | 14.19 | 14.45 | 12.80 |
| 20 | 50.05 | 50.60 | 49.88 | 11.20 | 11.30 | 11.00 |
| 27 | 32.00 | 32.62 | 30.25 | 10.83 | 10.95 | 10.00 |
| 29 | 38.14 | 37.85 | 37.94 | 11.18 | 11.10 | 11.05 |

*Average 2 tests.

## SUMMARY

62. (1) It was shown that the so-called sensitivity to section is a property of all cast metals, and not an exclusive property of cast iron.

(2) Earlier work of the author was reviewed briefly, in which he determined the influence of the alloy elements silicon, phosphorus, nickel, chromium, molybdenum, aluminum, etc. on the properties of cast iron of different thicknesses of cross-sections, and of separately cast round bars tested for transverse strength, hardness, and carbide content. The test iron was melted in the crucible and electric furnaces.

(3) New experiments were discussed, in which the influence of the elements silicon, phosphorus, nickel, chromium, molybdenum, tungsten, and copper on the properties of cupola cast iron of increasing section was determined, using hollow box-shaped castings for test pieces.

(4) The tests of (3) were made for tensile, transverse, and shear strength, hardness and carbide content.

(5) The representation of real strength values, and of hardness and carbide content as well, as a function of the section, was made in the logarithmic form, as proposed by Coyle, Jungbluth, and Heller.

(6) The tests showed the unfavorable influence of silicon and phosphorus, and the favorable influence of nickel, especially when the latter was substituted for silicon.

(7) The influence of chromium, especially in combination with nickel, is favorable. In the absence of nickel, the hardening effect of chromium can be counteracted by not too high an increase in silicon content.

(8) Molybdenum has an effect similar to that of nickel, but does not have so favorable an influence in equalizing hardness as nickel.

(9) Tungsten and copper have a favorable, but milder effect on the influence of section, or may be neutral.

(10) A new shear test is described, which is cheap and easily carried out; it is especially suitable for testing the variation in properties within a certain cast section.

(11) The results of the new shear test show the influence of the elements according to the proceedings given in (6) to (9).

(12) A simple relation between the different properties of gray iron was developed, and critically evaluated.

(13) The results from single separately cast bars were compared with those obtained from the hollow box castings.

# Melting Nonferrous Alloys in a Cupola Type Furnace

By W. C. Alvin*, Chicago, Ill.

**Abstract**

*In this paper, the author tells of his experience melting nonferrous alloys in the cupola. The furnace is much the same as that in general use in iron foundries, except for a few changes to adapt it to nonferrous melting. The fuel used is a by-product pitch coke, called a fixed carbon fuel. A metal-fuel ratio of 12 to 1 is usually maintained. Metal and fuel are charged alternately. The metal can be tapped 1¼ hours after starting the fire, and after that, tapping is continuous. Necessary replacements of lead and zinc are made to the ladle after tapping. One addition to the usual cupola equipment is a smoke arrestor, needed because of the heavy zinc oxide fumes. Among the advantages given for cupola melting are (1) the convenience of continuous pouring; (2) the flexibility of the furnace, which can be operated entirely to suit production requirements; and (3) the low melting cost.*

1. The method of using a cupola for production melting of nonferrous metals is not very old. It was introduced to the brass foundries only a few years ago by the Barrett Company as an outlet for one of their by-products. The principle is not new, as this method has been tried numerous times by foundries casting both brass and iron. However, that work was more or less of an experimental nature.

2. Only a few alterations were necessary to adapt the cupola in general use by iron foundries to the melting of brass. One of the necessary additions was the installation of a smoke arrestor, because of the heavy zinc oxide frames.

* Superintendent, Imperial Brass Mfg. Co.

Note: This paper was presented at a session on Nonferrous Founding at the 1934 Convention of A.F.A.

3. The cupola at the plant with which the author is connected is of the regular size used by practically all nonferrous foundries equipped for cupola melting. It is 36 in. outside diameter and 22 in. inside diameter after lining, and is equipped with the customary four tuyeres. The 36 in. diameter extends 10 ft. 4 in. from the bottom of the melting zone, then tapers to a 2 ft. 4 in. diameter where it protrudes through the roof. The total height is 33 ft. from the floor.

## RAMMED LINING USED IN CUPOLA

4. The melting zone is insulated with a layer of sil-o-cel and fire-brick and a rammed lining of a special refractory material known as carbofrax No. 3; the remainder of the stack is lined with fire-brick. A different lining is used in the melting zone than that originally specified and installed by the contractor. Experience has shown that the block type of lining is impractical for our operation and not economical when compared to the rammed one. Ordinarily, the rammed lining will last for four months of continuous use if it is patched daily where necessary and kept in first-class condition. An air chipper is used for conditioning the melting zone and for chipping off the slag and other foreign substances. This saves a good deal of time.

5. Opposite the slag hole opening is a clean-out, used for patching and preparing the drop bottom when put in place preparatory to starting the fire. After the coke has begun to burn, the opening is sealed with fire-brick and patching cement. The slag opening on the opposite side is used only when it is necessary to draw off the slag. This is done by opening the slag hole, which is cemented shut with fire-brick, and putting on additional blast. After all slag has run off, the hole is sealed and operations resumed.

6. Impurities which make it necessary to slag off are sand and other dirt on gates and sprues; shop scrap, and skimmings; imbedded sand from sand blasting; and other impurities which unavoidably occur in castings practice. When the slag is blown off, the entire room is filled with gases, fumes and smoke thrown off by the blast. Unless the shop is properly ventilated, these fumes are quite a problem. They can be lessened by installing a movable hood with suction on the exhaust end.

7. After starting the fire, the cupola can be tapped in 1¼ hours, after which the operation is continuous. Metal is taken out at the rate of a ton per hour and production can be increased 10 or 15 per cent if necessary.

8. In the case of gas, coal, and similar furnaces, all the metal usually is ready at one time, necessitating all molders and helpers to pour at the same time. With the cupola, the pouring-off is continuous and is done by a pour-off gang. Under such conditions, the molders can produce more without being called on to pour off their molds.

9. This type of furnace can be operated to suit the number of molders or amount of metal required. If production is low and certain output is required every day, the cupola can be started late in the day. However, it can be operated up to 16 hours a day, and can take care of a number of shifts of operators, cutting down only long enough to patch if required. This type of furnace is very flexible and can be operated entirely to suit the production requirements.

10. One-half to three-fourths of an ounce blast pressure, 350 to 375 cu. ft. of air per minute, are required for melting operations. The temperatures above the tuyeres is approximately 3100 deg. Fahr.; the pouring temperature into the crucible is between 2200 and 2400; the stack temperature is 1800 to 1900 deg. Fahr.

## METAL CHARGED WITH ELEVATING BUCKET

11. Metal and fuel are charged with an elevating bucket, operated from the floor level, which does not require any manual feeding or charging when brought up to the charging door. The bucket tips and discharges its contents into the charge door. Charges of metal and coke are alternated by the man in charge of cupola operations, who also maintains the fuel level and discharges all other duties except tapping and slagging off.

12. At some plants the charging is done on a separate floor of the same elevation as the charge door. The material is dumped and pushed into the charging door. This is an ideal arrangement if space permits.

13. The fuel used is a by-product pitch coke, termed a fixed carbon fuel, derived from processing in the tar industry. The chemical analysis of this coke is:

| | |
|---|---|
| Fixed carbon, per cent | 98.5 |
| Sulphur, per cent | 0.4 |
| Ash, per cent | 0.7 |

It has a high compressive strength because, although very hard, it is porous.

14. In operating the cupola, the fuel level must be maintained to insure proper production. This can be accomplished only through experience in operating this equipment.

15. Although the cost of this fuel seems high, a different picture appears when the cost of metal melting is analyzed and compared to oil, coal, or gas melting costs.

## HIGH FUEL-METAL RATIO POSSIBLE

16. We have had as high as a 16 to 1 metal-fuel ratio, but that was for a short duration of time at constant production when it was necessary to bleed the furnace and when the smoke arrestor was not used. Under ordinary conditions an 11 or 12 to 1 ratio is maintained, and a 14 to 1 ratio is not uncommon. Since the installation of the cupola the cost of fuel has ranged from $2.54 to $2.77 per ton of metal melted. This figure does not take into consideration other costs, such as labor, repairs, fire-brick, and kindred items which make up operating expense.

17. As an average over a number of years, the cupola melting cost figures 32 per cent to 35.5 per cent of the gas melting cost. However, due to the staggered condition of business, the cupola has not been operated a full day and this fact increased the cost per ton of the metal melted. Under recent business recovery, a decided improvement has been shown that reflects to the credit of the cupola.

18. The cupola will not melt every type of copper alloy successfully and economically. The controlling factor is the zinc loss; therefore, the metal melted should not contain a large amount of zinc. The most practical alloy is the red-brass mixture containing not less than 78 per cent copper, with the zinc content kept under 5 per cent and the lead under 10 per cent. Since the greatest losses occur in zinc and lead, these elements must be held to as low a percentage as possible. We have our own alloy and it is used exclusively in this cupola. We prefer to melt a single alloy instead of running several alloys on the same day, as is the custom in some foundries. However, rotation melting can be accomplished in the cupola by draining the old charge and immediately putting in the new one. This may not be good practice, but it can be done when it is necessary to get the full benefit of the cupola.

19. The metal losses are high as compared to other methods of melting. In an electric furnace, the metal loss is practically nothing. In a coal fired crucible, the losses are very low, about 2

per cent lead and 12 per cent zinc. Losses are slightly higher with a gas fired crucible, averaging about 4 per cent lead and 15 per cent zinc. However, in cupola melting, the lead loss is 15 per cent and zinc is 45 per cent. These figures are higher than claimed by others, but are proved by analysis. Loss of copper and tin is negligible. The low melting costs counteract this loss of metal.

20. Our rule has been to add the necessary replacement of zinc and lead to the ladle when tapping. This is, of course, the most economical method, for no oxidation of any consequence takes place from then until pouring.

21. The question may be raised as to whether the metal is of the proper mix. If alloyed ingots are used where possible, and not too great a quantity of virgin metal is added, the metal mix is very good and uniform. A few ingots or bricks of virgin metal alloy properly without any trouble.

22. The degree of mixing may be varied according to the kind of metal charged. We use nothing but regular ingots, gates and sprues, and shop scrap. We found the use of borings a false economy, because the losses increased when they were used. The blast has a tendency to blow the borings through the stack into the atmosphere with the fumes, as was clearly evident on the roof around the stack before the smoke arrestor was installed.

## SMOKE ARRESTOR IS NECESSARY

23. The zinc oxide fumes emitted from the cupola stack constitute quite a problem in cities. We had thought that they would disappear into the air, but they did not. Instead, the heavy zinc oxide dropped toward the ground, and sometimes the entire neighborhood within a quarter of a mile of the plant has been covered with a grayish-blue pall.

24. Finally we had to put an end to this nuisance. After a few unsuccessful trials, using both home-made and commercial smoke arrestors, we decided to have the Barett type installed. This equipment was developed at the Federal-Mogul plant in Detroit by the Barrett engineers, and had the approval of the Detroit smoke department, as well as of the Chicago smoke abatement bureau.

25. The smoke abator consists of a spray box connected to the cupola by a breeching. The hot fumes (1900 to 2200 deg. Fahr.) pass through this spray box through a "U" shaped passage, where water is sprayed by a revolving roller that is immersed

about 1 in. below the water level. The water is obtained from the overflow from the filter tower. From the spray box, the gases pass through a conductor to the blower, and then into a cylindrical filter tower. A 4 in. layer of common coarse gravel, under a constant spray of water, is used as a filter. The lighter fumes pass through this layer of stones into the atmosphere. The heavier portion recirculates through a by-pass and again goes through the blower and filter-tower, until it is broken up into lighter fumes that can pass through the filter.

26. The gases which have passed through the filter have become saturated with steam and when they dissipate, become practically invisible within 50 to 100 ft. from the stack.

27. This smoke arrestor is not just a toy for us because it has caused us much grief and worry. Even when it is in operation there are numberless things which have caused us trouble. The chief concern is the fact that zinc oxide builds up in a hard cake form, in different locations in the equipment, until there is almost no passage left for the fumes.

28. We do not attempt to reclaim any of the zinc oxide waste, as the market price does not warrant the installation of settling tanks for this purpose although some companies use zinc oxide for paints or for material they manufacture.

## DISCUSSION

*In the absence of the author, this paper was presented in abstract form by R. L. Binney, Binney Castings Co., Toledo, O.*

T. C. WATTS[1]: We use a cupola of the same type in our shop but do not find it necessary to use a zinc arrester because the alloys that we melt are not high zinc alloys. I should think that if a zinc arrester were needed, it would indicate too large a loss of metal. We do not find that the high zinc alloys can be melted practically in this type furnace. Otherwise, it is a nice, fast-melting furnace and, for some purposes, very desirable.

J. L. WICK JR.[2]: This furnace is a very valuable unit, especially on capacity production. If you have the proper set-up, there is very little labor in connection with the melting of great tonnages.

E. F. HESS[3]: We have had one of these Barrett type furnaces in our plant for several years. Like any other type of furnace, it is more suited to melting certain alloys than others. I believe this limitation to be true of all types of melting units. You cannot melt every type of alloy in each type furnace to the best advantage.

[1] [2] Falcon Bronze Co., Youngstown, O.
[3] Ohio Injector Co., Wadsworth, O.

We have found that melting the 85-5-5-5 alloy in this type furnace is very satisfactory from the standpoint of getting good castings. I will say that we have had some trouble getting metal of the higher temperatures but it should deliver metal under 2200 degrees Fahr. very satisfactorily.

The tensile strength of the metal from this furnace is just about the same as from any other type melting unit. As to melting loss, while I do not have our data at hand, I believe that it is a little more than in some other types of furnaces.

M. GREENBERG[4]: I had an experience some years ago with the type of furnace under discussion. We were doing work for the Pelton Water Wheel Co., San Francisco, and I had an experience making five, 5-ton bronze runners, but they were made of 88-10-2. We made them one at a time and melted the metal in the iron foundry in a regular Barrett cupola. We used about 75 per cent new material—copper, tin and zinc—and about 25 per cent ingot metal which was approximately 88-10-2. We added the zinc and tin in the ladle and got very good castings. We poured it all at one time and the tensile strength came up to the specification for 88-10-2.

SAM TOUR[5]: I wish to compliment Mr. Alvin for his willingness to give the information contained in this paper and obtained from his own experiences with a cupola type furnace. I do not wish to criticize this paper itself nor its author, but it seems that emphasis should be placed on the fact that the results reported are applicable to a very large extent to only the one installation and should not be considered as representative of all installations of this type furnace.

In paragraphs 5 and 6, the operation of slagging off is described as intermittent, requires additional blast and fills the room with gases, smoke and fumes. Such practice is not required in all cupola installations on nonferrous metals. The slag can be made fluid and can be tapped off continuously without the application of additional blast.

In paragraph 10, reference is made to a blast pressure of ½ to ¾ oz. This is, of course, dependent on the nature of the charge and the height of the total charges above the melting zone. The closer and denser the charges and the larger the number of charges, the greater will be the blast pressure required.

In paragraph 17, it is stated that the cupola melting cost figures 32 to 35.5 per cent of the gas melting cost. In the previous paragraph 16, reference was made to a fuel cost not including labor, repairs, fire brick, etc., in a later paragraph reference is made to the higher metal losses encountered in this type furnace. True melting costs must include all of these items. It is unfortunate that such comparable true melting costs are not given in the paper.

In paragraph 19, the statements are made that "In an electric furnace, the metal loss is practically nothing. In a coal fired crucible, the losses are very low, about 2 per cent lead and 12 per cent zinc. Losses

[4] M. Greenberg's Sons, San Francisco, Calif.
[5] Lucius Pitkin Inc., New York.

are slightly higher with a gas fired crucible, averaging 4 per cent lead and 15 per cent zinc." These are hardly in accord with actual results in many other plants. Metals are lost in electric furnaces as well as in other furnaces. In addition to lead and zinc losses, there are also losses of copper and tin. These losses are not negligible. In the course of a year, they may well run into a sizeable item.

It is surprising to find how little importance is placed on metal losses by many nonferrous foundrymen and it is surprising to find many nonferrous foundries where no determinations of actual metal losses have been made.

Paragraph 10 gives a stack temperature of 1800 to 1900 degrees Fahr. whereas paragraph 25 refers to hot fumes at 1900 to 2200 degrees Fahr. Such temperatures indicate very poor fuel efficiency, which goes with very open charges and very low charges and high blast pressures.

It seems to me that information which is above reproach should be presented at these meetings. I do not want to be too critical of this paper, but I do not think it is fair to the Barrett Company, who are doing their best in the development of this furnace, and those companies who are using this furnace satisfactorily, to let these statements go unchallenged and, on the other hand, I do not think it is fair to some people who are considering buying these furnaces, to let some of the statements that are too favorable to the Barrett equipment go unchallenged.

It is my feeling that we should all be very careful that in these papers we present a true, unbiased picture of actually what happens. It is my feeling also that those people who are in a position to give corrective information should consider it their duty to present such corrective information as discussion of papers presented.

JEROME STRAUSS[6]: As a matter of historical interest, at the time that I was connected with the Naval Gun Factory, Washington, we did some experimenting along this line in cupola equipment that was used primarily for iron. The work was largely on 88-10-2 but someone tried to recover aluminum bronze scrap in the cupola. The point is that 10 or 12 years ago, cupola melting of nonferrous alloys was being tried. At the same time, I am sure that it was being studied elsewhere because I recall having seen some publications touching very briefly upon work of this same nature.

In handling 88-10-2, the quality of the product obtained was fair. After the small zinc losses and the rather large tin losses had become established, additions could be made to correct for them in the final alloy but quality was not quite as high as in the case of castings produced by crucible practice and the use of the cupola for melting 88-10-2 was discontinued.

The results obtained with aluminum bronze were rather disastrous and one attempt was sufficient to cause cessation of that practice.

[6] Vanadium Corp. of America, Bridgeville, Pa.

# Cupola High Test Cast Iron*

By R. P. Lemoine,** Paris, France.

**Abstract**

*Recent developments in France in the production of high test cast iron have been along two lines. The first is the production by foundries of special low carbon pig iron from steel scrap which formerly was made in specially constructed blast furnaces and the treatment of the pig iron as it comes from the cupola with soda ash, which acts as a scavenger rather than as a desulphurizer. The second development is the special action of certain final additions on graphitization. The paper gives the chemical requirements of high test cast iron of low carbon content and explains the reasons for certain silicon percentages being desirable. The use of ladle additions such as silico-calcium, silico-chromium and the recently introduced low-carbon, silico-titanium with low melting point is explained. Directions are given for the manufacture of the special pig iron in the cupola and the charges to be used for producing the final product, high test cast iron.*

1. The author sent a paper[1] to the 1929 meeting of the A.F.A., in which he recalled the evolution in France of the production of high test cast iron since the well-known semi-steel process was introduced. The present paper treats of what has been done during the past five years. The author wishes to be excused if too many references are made to his previous paper but it probably is better not to repeat details already described.

2. The feature of the recent improvements in high test cast iron production is that they have been governed more than ever by cost considerations. Customers require much lower prices than they were disposed to pay some years ago and an ever increasing standard of quality.

3. This high standard of quality can be reached conveniently when an electric furnace is used but, since the cost of electric

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* Annual exchange paper of the French Foundry Technical Association.

** Consulting Engineer and Professor, Foundry High School.

[1] R. P. Lemoine, *"High Test Cast Iron,"* Transactions A.F.A. vol. 37, 1929, pp. 259-288.

Note: This paper was presented at a session on Cast Iron Founding at the Fifth International Foundry Congress and 1934 Convention of the A.F.A. in Philadelphia.

power has not diminished in many places in the same proportion as selling price of the castings, many foundrymen have been obliged to try to improve the quality of their cupola production and to reserve their electric furnace for special jobs which demand higher prices.

4. For this reason, the most interesting developments have been in cupola melting and only this aspect of the question will be considered.

5. The paper is divided in two principal parts: The first deals with the chemical compositions adopted to get the best results and the second gives some details of the practical operations.

## CHEMICAL COMPOSITION IS DISCUSSED

6. The low carbon theory for high test cast iron had its beginning in 1929 and was considered at that time by many foundrymen as an interesting subject for congress papers rather than a really practical basis to improve the uniformity of strength throughout the different sections of a casting. However, the practicability of the high test cast iron theory has been proved sound and many foundries in France now produce important castings with carbon contents decidedly under 3 per cent.[2]

7. Practical results show that this is the best way to secure no larger difference of strength than 15 per cent between the strongest and the weakest parts of the same intricate casting when the test bars are cut from the casting itself. This compares quite favorably with the differences of 40 to 60 per cent which are frequent for semi-steel. The average and maximum strength values also are much higher.

8. At first, the typical composition advocated to secure such results was:

| | |
|---|---|
| Total Carbon, Per cent | 2.50 |
| Silicon, Per cent | 2.50 |
| Manganese, Per cent | 0.80 to 1.15 |
| Sulphur, Per cent | under 0.08 |
| Phosphorus, Per cent | under 0.30 |

9. This composition first was secured by using an electric furnace to produce the iron and its practical study dates back to the first attempts to cast synthetic iron directly in molds. This was tried later with the duplex process (cupola-electric furnace)

[2] As far as we know, this theory has been much advocated and applied in the U.S.A. by R. S. MacPherran.

and, finally, with cupola alone. To accomplish this, the cupola was charged only with steel scrap and ferro-alloys or with a mixture of steel scrap, ferro-alloys and special low carbon pig iron. The paper already referred to described in detail all these points.

10. Cupola iron of similar analysis is used in the production of tons of castings of every description; including locomotive cylinders, Diesel engines, turbine casings and has proved that it is an advantage to increase the carbon content somewhat and diminish the silicon.

That is true for the following reasons:

## THEORY IS PROVED

11. It has been recognized that 2.50 per cent carbon seems to be a critical point for shrinkage and porosity. Under this carbon percentage, such defects become frequent and make the production of sound intricate castings difficult. With the lower carbon irons, it is necessary to gate and feed the castings as in steel foundry practice. When the carbon content is raised to between 2.55 to 2.70 per cent, difficulties are much less and the usual methods adopted in iron foundries to give good, sound castings are successful.

12. This tendency to some defects when the carbon content is under 2.50 per cent is increased by superheating the iron, especially when that operation produces an iron in which the graphite has the so-called "eutectic" shape and is arranged in cells. Such a structure, characterized by a black and dendritic fracture of the iron, has been recognized as rather poor in impact properties and static strengths. In practice, it is avoided by methods described at the end of this section.

13. Some important features have inclined the foundry metallurgist to lower silicon under the initial figure of 2.50 per cent. When the carbon content is increased for reasons already stated, it seems natural to decrease the silicon to maintain the same total effect upon graphitization in the iron. This is not strictly necessary because there is a certain interval in the silicon percentages in which cast irons with sufficiently low carbon contents do not cease to be pearlitic for different usual cooling speeds. Still, the decrease is practiced but for other reasons, among which the two following are important:

14. First, impact resistance has proved to be higher with the lowest silicon figures of the "pearlitic interval" than with the

highest. This seems to be a direct effect of the silicon, at least when that element comes from the raw material used to produce the iron or when it is added as a ferro-alloy mixed with this raw material before melting.

15. Secondly, as many high test castings are used at certain temperatures where there can be a beginning of decomposition of pearlite, an attempt is made to delay this occurrence by lowering the silicon content.

16. When these two features were taken into consideration, some foundries did try to fix the silicon content of their low carbon high test cast iron near 2 per cent. This proved interesting for electric furnace products and the author remembers having produced an order of 145 tons of castings, averaging 3 Cwts. each, with that type iron in 1931. The strength was tested on bars cut from a 3-in. section of some of the castings and the tensile results were all between 41,000 and 49,000 lbs. per sq. in.

## LOW SILICON TROUBLES LISTED

17. On the other hand, 2 per cent silicon was found to be, in general, too low (if connected with a 2.60 or 2.65 per cent carbon) for cupola irons produced by the usual method with steel charges. The chief troubles were:

(a) Lack of "Castability," resulting in short runs or round edges of thin sections and blow holes in others. Air and gas bubbles had no time to escape before the iron solidified and they remained entrapped.

(b) Too strong tendency to chill near the skin and important strength heterogeneity between thin and thick sections.

(c) As a result of (b), iron too hard to machine in some parts of the castings.

18. Following the necessity of low cost, which required the use of as much steel scrap as possible in cupola charges, the two properties, castability and graphitization, have been studied and details about the former will be given in the next section.

19. Regarding graphitization, it has been found that the effect of silicon may be different when it is added to the solid material before melting than when it is dissolved afterwards in the liquid iron.

20. The author remembers mentioning in different papers[3] about the production of electric furnace cast iron, that he preferred

[3] Loc. Cit., p. I., R. P. Lemoine, "Les Fontes a Haute Resistance. Progres Recents". Rapport Congres International de Liege 1930, Section Metallurgie, p. 805.

to add the silicon when the iron was liquid and hot. In a general way, he mentioned, with his colleague A. Portevin[4], the important influence of the time of this silicon addition and the concentration of silicon upon the characteristics of graphitization.

21. In cupola melting of steel scrap, conditions are similar and silicon added when the liquid iron comes out from the spout seems to be more active in promoting graphitization during rapid coolings,[5] than when incorporated in the charge. Such an action, which is not accompanied, at least in low carbon irons, with graphitization of the pearlite in the internal part of thick sections, is interesting since it tends toward uniformity of structures and strengths throughout the different parts of intricate castings.

## EXPLANATION IS ADVANCED

22. This feature, which probably can be connected with the effect of the silico-calcium addition in the Meehanite process, recently has been explained tentatively by two hypotheses. One hypothesis, due to J. G. Pearce, England, admits that the final silicon addition creates graphite nuclei in the melt and innoculates the iron. The other, sponsored by A. LeThomas, France, ascribes to the addition a deoxidation effect on the iron. That effect also is said to help graphitization.

23. The author is not in position to discuss these two tentative explanations nor to propose a third. He only wishes to take this opportunity to recall some points which have some connections with the subject.

24. There is much to be said and still more to be studied about the equilibrium mechanisms of carbon in liquid baths,[6] about the possible intervention at the moment of the additions of dissociation heats and about special associations of silicon with iron.

25. Since Portevin and Perrin have explained[7] the effect of local concentrations at the time of certain additions to precipitate non-metallic inclusions, it seems possible that other local concentrations can promote a special formation of graphite nuclei in a liquid iron, even if some moments after, the added element appears to be diffused and well distributed in the bath.

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[4] Congres International de Liege 1930, Section Metallurgie. Rapport sur la Discussion des Memoires, pp. 31-32.

[5] L. Martel. Thesis of Foundry High School, Paris 1929.

[6] Portevin, Congres International de Metallurgie, Liege 1922.

[7] Portevin and Perrin, "Contribution to the Study of Inclusions in Steels," Iron & Steel Institute, vol. 127, May 1933, pp. 153-187.

26. Whatever the mechanism, a striking example of the influence of time, nature of the addition, and temperature of bath on graphitization is given by irons containing 15 per cent silicon and used to resist acid corrosion. By proper manipulation of melting procedure, the carbon in the castings can be all combined (usual case) or, on the contrary, all precipitated in minute graphite flakes (special machinable product) with the same final composition and the same cooling rate in the molds.

## CITES EXAMPLE OF CARBON CONTROL

27. However, if we turn back to our subject, it appears that the addition of at least a part of the silicon in the ladle or in the spout in general is beneficial to cupola high test cast irons. When this addition is coupled with other precautions described later, it increases fluidity and, by its influence on graphitization, allows the successful production and casting of irons with not more than 2 or 2.15 per cent silicon coupled with 2.60 to 2.65 per cent total carbon.

28. The best way to add silicon probably is to use 90 per cent ferrosilicon which dissolves easily in cupola iron produced with steel scrap. On account of very small losses (in general not more than 5 per cent), the cost is about the same as if the silicon were added as 25 or 45 per cent ferrosilicon in the charges. In many cases, it has proved more economical.

29. This practice of ladle additions has been highly developed during the past few years and other silicon bearing alloys are used commonly in addition to the silico-calcium already mentioned. The most well-known in France is a silico-chromium alloy of low melting point which dissolves easily and is paramount when some chromium is desired in the iron to produce special hardness or pearlite stability at high temperature.

30. An interesting composition of a high test cast iron of this type follows:

| | |
|---|---|
| Total Carbon, Per Cent | 2.60 |
| Total Silicon, Per Cent | 2.20 |
| Manganese, Per Cent | 0.80 |
| Sulphur, Per Cent | 0.06 |
| Phosphorus, Per Cent | 0.15 |
| Chromium, Per Cent | 0.30 |

31. A new ladle-addition alloy recently has been introduced. It is a low melting point silico-titanium containing less than 1 per

cent carbon. The first practical results of its use are extremely promising. This addition seems to allow a further substantial diminution of the silicon content and under such conditions to have a beneficial effect upon the dimension and uniformity of graphite as well as the stability of pearlite at high temperatures. Such an addition can be coupled advantageously with a silico-chromium addition. The titanium content always remains low, 0.10 to 0.20 per cent.

32. In concluding this section, let us note that, as already mentioned by J. G. Pearce, ladle additions prevent bad supercooled structures, such as cellular eutectic graphite coupled with ferrite.

## EXPLAINS MELTING METHODS

33. Production of high test cast irons, corresponding to the chemical compositions referred to in the preceding section, can be made in a foundry cupola either with all steel charges or with a mixture of steel scrap and special low carbon pig iron.

34. The second method, which is the better of the two for production of uniform results, was described in the author's paper of 1929. It was stated there that the special pig iron was produced in specially adapted blast furnaces. Production has been developed since that time and methods now used are considered in some French foundries to be approximately equivalent to those used in the duplex and electric furnace processes.

35. An important evolution must be noted about the special low carbon pig iron. Various blast furnaces and steel companies have tried to enter the field with so-called "refined iron," which is a steel scrap product.

36. Good results are obtained with this last material but, as it is more costly than the special blast furnace iron, some foundrymen have tried to produce it in their own cupola. This attempt was successful and constitutes the most recent improvement. It now is the normal routine process adopted by some leading foundries. For this reason, it will be described in some detail.

37. Assume, for instance, that we want to produce with a normal foundry cupola an iron having the chemical composition indicated on page 6 to make castings such as Diesel liners or heads, and locomotive cylinders. The all steel scrap charge process can be used successfully, but there always is some danger of deficient fluidity, blow holes, shrinks, and other defects if the

scrap is not well adapted or if the heat is not run perfectly. Results are much more certain and consistent if the following process is adopted:

### PREPARES LOW CARBON PIG IRON

38. First, prepare a low-carbon pig iron from all steel charges and take the necessary precautions to have a clean and washed product. Then perform the final melting with charges composed of certain proportions of low carbon pig iron, shop returns of high test cast iron, such as gates, risers, etc., and clean steel scrap.

39. *Pig Production.* The chemical composition aimed at is, for instance:

| | |
|---|---|
| Total Carbon, Per Cent | 2.20 or less |
| Silicon, Per Cent | 1.50 or 2.00 |
| Manganese, Per Cent | 1.20 or 1.50 |
| Phosphorus and Sulphur, Per Cent | Low |
| Chromium, Per Cent | None |

40. Obviously, the carbon must be as low as possible so that it does not exceed the final figure desired, taking into consideration carbon increase on remelting. Silicon is limited to diminish the total losses after the two meltings but it must be substantially present in the pig composition so as to give the low carbon iron a sufficient fluidity and, also, to minimize the carbon pick-up during the second melting. Manganese is relatively high to make as low as possible the sulphur pick-up and avoid over-oxidation. In general, the charges for this operation are composed of: Selected and clean steel scrap mixed with the necessary quantity of 15 or 25 per cent ferrosilicon and spiegel or silico-spiegel.

41. The cupola adopted has a low coke bed and, preferably, a fore hearth or front ladle which should be heated to a red heat before tapping. Figures for blast pressure, weight of metal and coke charges, composition of slag, etc. have been given in the author's previous paper.

42. The effects of soda ash on the liquid iron before casting the pigs has been interesting. The desulphurizing effect of soda ash is well known and has been studied by many authors but, in this case, another effect of this material is considered much more helpful than the diminution of the sulphur content. Soda ash also functions like a "scavenger" and, as far as this can be roughly

estimated with the microscope, it actually diminishes the non-metallic inclusions in the iron.

43. It seems probable that soda ash increases the fusibility and fluidity of these non-metallic materials (silicates) and allows the small particles to coalesce to form larger particles which rise to the slag more quickly. This washing or purification is characterized by an increase of fluidity or "castability" of the iron as measured by the spiral test. Taking account of the decrease of temperature, the iron runs more freely after the action and this occurs even if the desulphurization has been small. In other words, the increase of "life" is not related to the sulphur content.

44. "Soda washing" is considered to be an important part of the process and produces a pig iron with a quality equivalent, as a raw material, to the best electric furnace or open-hearth "refined" pig irons. It is not costly because less than a pound of soda for a cwt. of iron generally is sufficient but it must be done with care to give good results.

## TIME IS IMPORTANT FACTOR

45. The success depends to a large extent upon the intimate mixing of the soda ash with the iron in the cupola's fore hearth or front ladle, and upon the time given the particles to rise to the slag before casting the iron. It is necessary to slag off several times with lime, and precautions must be taken about the quality of the lining of the ladles in which the operations are performed. Generally 1 to 2 tons of iron are treated at a time. The alloy afterwards is cast on a sand pig bed or in ingot molds.

46. The question arises as to whether or not ingots are preferable to sand cast pigs for the next remelting. Theoretically, it would be so and the author has made some practical tests to see if this has a positive influence upon the quality of the final product. The comparative results are not striking, but they convey the impression that casting this first iron in ingots probably is better.

47. Several methods of procedure are used to produce the special pig iron in the foundry. Some foundries prefer doing the work each day after the normal casting heat when the cupola is hot. In this instance, they prepare pigs for the next day's consumption. Other foundries prefer to devote a whole day to prepare the pigs for several days or a week.

48. This last method means that less chemical analysis must be done on the material. Control analyses are made only for total

carbon and silicon. Those elements are determined on the first and last ladles treated with soda ash. If there are only small differences between the results and if the cupola has operated uniformly during the heat, the metal is considered to have a uniform analysis. In case of the contrary, chemical analysis is made on samples from intermediary ladles, and the heat is divided into two or more lots according to analysis.

49. When production of special pig iron becomes common work in the foundry, the workers rapidly learn to detect eventual irregularities and decide to separate lots of pigs as soon as they are cast. This makes chemical control more easy and efficient. Fracture examination of some pigs or specially cast samples assist in control.

## COMPOSITION OF CHARGE USED

50. *Final Melting.* The final melting usually is performed in the same cupola used for pig production. The composition of the charges depends to a great extent upon the chemical composition of the pigs used. It is often the following:

| | |
|---|---|
| Low Carbon Pig Iron, Per Cent | 40 to 50 |
| Shop Returns of the Same Fabrication, Per Cent | 20 to 15 |
| Clean Steel Scrap, Per Cent | 30 to 35 |
| Eventually: Silico Spiegel | |

A typical charge for a cupola operated at 4 tons per hour would contain 500 kilograms (1100 lbs.) metallic material and 65 kilograms (143 lbs.) of coke. Other operating data includes blast pressure in the wind box, 450 mm. of water (10.25 oz. per sq. in.), tuyere area, 1/6 of area of cupola and height of coke above tuyeres, 500 mm. (19.68 in.).

51. Such figures, are only indicative. As already stated, calculations provide for a ladle addition of silicon. When this addition is made with 90 per cent ferrosilicon, the alloy dissolves fairly easily if large pieces are placed across the iron stream in the spout channel of the cupola or of the forehearth and set in place with a steel bar. The pieces are dissolved like sugar in water and it is striking to see the difference in the color of the iron before and after the silicon has been dissolved. The color is much brighter after dissolution due to an exothermic reaction which does not

seem to be caused only by oxidation if it is considered that chemical analysis generally shows small losses.[8]

### DESCRIBES METHODS OF ALLOY ADDITION

52. The smallest pieces of ferrosilicon can be added in the stream of iron falling in the front ladle or forehearth. Precautions must be taken to poke the small pieces into the bath because they have a tendency to float. If silico-calcium is used, it also must be poked thoroughly on account of its low specific weight and its ability to burn at the surface of the iron. Silico-chromium and silico-titanium usually are added in small pieces in the iron stream and the bath must be stirred well before casting. The first two additions tend to increase the fluidity of the iron and the last two have no positive influence on that characteristic. Their quantity always is small.

53. It is not profitable to treat this last iron with soda ash. In this case, the soda ash does not benefit the fluidity.

### CONCLUSION

54. The author has explained recent developments in the production of high test cast iron in some of the leading French foundries. Two improvements have occurred which appear to be important.

(1) Double melting of a part of the steel scrap used as raw material coupled at least at one stage, with a soda ash treatment. The soda ash treatment is considered more as a scavenging or cleaning treatment than as a desulphurizing operation. This is in line with the general tendency of modern metallurgy to utilize the beneficial and rapid effects of very fluid slags.

(2) Special action of some final additions on graphitization. Such action is especially strong for high cooling speeds and leads to greater uniformity of structure throughout different sections of the same casting.

[8] R. P. Lemoine, *"Les Fontes a haute Resistance, Progres recents,"* Congres International de Liege, Section Metallurgie, 1930, pp. 801-809.

## DISCUSSION

R. S. MACPHERRAN,[1] (*Submitted in Written Form.*): In commenting upon this most excellent paper, I would say that I have no criticisms to make but only praise for the clean-cut and concise manner in which the author has made his points.

Our experience with high test cast iron containing carbon under 2.50 per cent has been very similar to that of the author and we now try to keep it between 2.50 and 2.80 per cent. We also have been troubled with the dentritic fractures referred to and have been able to cure such trouble in a manner similar to the one described.

The author states that his impact resistance has proved to be higher with the lowest silicon figures of the "pearlitic interval" than with the highest. I am sure we would all be much interested in knowing what method of impact testing was adopted by the author and what type microstructure he found gave the best results.

In regard to the "too strong tendency to chill next to skin" and also finding the iron too hard to machine in some parts of the casting, I would say that these troubles are sometimes helped by the addition of 1 per cent nickel. This, of course, increases the cost of the metal per pound but where labor is paid a high rate per hour, it is sometimes cheaper to add alloys which will reduce the number of hours spent in machine work. For example, if a shop is paying 80 cents per hour for machine work they can afford to add more alloys to make a casting machinable than where the shop is paying only 20 cents per hour for machine work. It has some times occurred to me that this was one of the fundamental differences between this country and Europe. We often use alloys where they claim they cannot afford to put them in. It would seem, therefore, that the question of wages should always be considered when discussing the economy of alloy additions.

In agreement with the author (paragraph 27), it has also been our experience that the addition of at least a part of the silicon in the ladle is beneficial to high test iron. I note that the author uses a 90 per cent ferrosilicon. We have used this and have also tried a ferrosilicon containing 50 per cent silicon and 25 per cent manganese and have had good results with both. We have never tried the silicochromium alloy to which reference is made. I believe, however, this might be especially useful in helping to remove the dendritic structure. The analysis the author gives in paragraph 30 is much like the analysis of the iron used here except that it is a little higher in phosphorus and chromium.

We have made low carbon pig iron for cylinder use by much the same method described by the author but have never been able to obtain the carbon as low as that cited. We have, however, sometimes bought the over iron or pigs made during the heat of a malleable iron furnace. This metal contains about 2.50 per cent carbon with a fairly low sulphur and manganese.

In paragraphs 37 and 40, the author refers to the character of the steel scrap in the mixture. We would be glad to hear his experience on the use of rusty steel scrap and whether he finds that newly cut rails or

[1] Allis-Chalmers Mfg. Co., Milwaukee, Wis.

clean steel gives iron of better quality than where a large amount of rust or oxide must be removed in the cupola.

We would also be very glad to hear the author's experience on the use of high test iron for steam turbine cylinders and whether in his experience high test iron can be safely used on such at a fairly elevated temperature. The question of growth is here a most important one and we would appreciate any information on European practice in regards to operation at high temperatures of an iron with carbon 2.50 to 2.80 per cent and silicon 2.00 to 2.25 per cent and with and without alloy additions.

MEMBER: Are there any data on any strength characteristics which have been obtained from the test bars?

R. S. MACPHERRAN: Such data were omitted from this present paper but were given in his previous paper.* Unfortunately, the author has referred only to his previous paper given in 1929. That paper included physical tests and quite a lot of cupola detail, giving the blast pressure and all such details of operation.

The A.S.T.M. specifications of 1931 gave only 33,000 lbs. per sq. in. tensile strength for high test iron. Their new specifications (Spec. No. A48-32T) require more than that. They give seven grades from 20,000 up to 60,000 lbs. per sq. in. tensile strength, although in these new specifications high test irons are not listed as such.

MEMBER: I would like to ask if there are at present any foundries in this country which are producing, on any sort of a tonnage basis, high test iron, something that can be used by the engineer structurally in fairly large quantities and costing something less than the semi-steels. Of course, I expect the cost to exceed that of common gray iron.

R. S. MACPHERRAN: A lot of foundries are making castings of high test iron. We have made some castings weighing as much as 58 tons in weight. The test bars averaged about 55,000 lbs. per sq. in. tensile strength, using an arbitration bar. The mixture would be between 81 and 84 per cent steel, depending on what we put in, either more or less scrap. It is always above 80 per cent steel. We attempt to control the carbon and that determines the amount of steel. We often use one per cent nickel in the ladle. The nickel increases the tensile strength slightly and improves the machinability.

MEMBER: Is there enough tonnage produced to establish any sort of a price range? We buy iron now, ordinary gray iron, in heavy tonnages, at $50 a ton. Is it possible at all, or practicable, to produce a high test iron for anything like that. in tonnage lots of say three or four thousand tons?

R. S. MACPHERRAN: We often put one per cent nickel in the ladle. Our high test iron without nickel costs about the same as the ordinary iron. You will have to make an allowance for any nickel used. This would amount to between ½ and ¾ cents per lb., depending on weight of castings produced from a given weight of iron in the ladle.

MEMBER: What has been the experience in connection with foundry

* Lemoine, R. P., *"High Test Cast Iron,"* TRANS. A.F.A., vol. 37, pp. 259-288 (1929).

rejections in so-called high test iron as compared to the irons that are of ordinary classes?

R. S. MACPHERRAN: After you have learned to control gates and risers, etc., there is no more loss in the high test than in the other irons. When properly handled there should be no trouble with this iron.

MEMBER: Are there not a lot of designs of patterns out today that are not suitable for a high test iron? Our experience has been that we are apt to get more shrinkage cracks on a job that is not designed for high test iron.

R. S. MACPHERRAN: We have not found it necessary to change our patterns.

ROBERT JOB:[2] In connection with the question just raised, I might say that in Montreal, in the foundry of the Canadian National Railways, high strength iron has been used for a number of years very satisfactorily, particularly in the manufacture of locomotive cylinders. In that case, there has been no change in the patterns. That is, the same thickness and the same general arrangement has been used as formerly with ordinary cast iron. We find, however, that with the higher strength iron very much better service is obtained.

In these castings, we use about one per cent nickel to improve the machinability. The thickness of the locomotive cylinders varies from about ⅞ to 1½ ins. or more, and the general plan has worked out very satisfactorily.

MEMBER: Has it been the experience of foundrymen that this high test iron has been successful in bringing back to the shops a lot of the work that has gone to the forging plants?

R. S. MACPHERRAN: It has not brought back any of our work from the forge shop, but it has saved patterns going to the steel casting plants. If you can get a test bar of cast iron showing 55,000 to 60,000 lbs. per sq. in. tensile strength, they will often leave that pattern in the iron foundry. We make cast iron and do not make steel, as it happens.

ROBERT JOB: I would answer "Yes" in reply to that question. My personal opinion is that the use of the high strength iron has cut considerably into the use of cast steel for certain purposes. The practice which I mentioned in connection with locomotive cylinders is a case in point.

One outstanding example of the use of high strength iron in place of cast steel, is the manufacture of locomotive driving axle boxes, weight approximately 500 pounds. A number of these were put into new locomotives in 1931 and are still giving excellent service and no failures have been reported. We consider this as an instance of widely differing casting sections, the thickness ranging from 1 inch to 2½ inches.

As we all know, a great many cast steel cylinders are used in locomotive practice, but with the high strength iron it has been found possible under our conditions to get excellent service without the use of steel, and we thus have something which can be manufactured readily in the gray iron foundry.

[2] Milton Hersey Co., Ltd., Montreal, Canada.

There is one point which is brought up in connection with the terms of what is meant by "high strength iron." This is a matter that has been given a great deal of attention by one of the sub-committees of the A.S.T.M. At the meeting last June some tentative definitions were given out to the Society and are under consideration at the present time, so that if anyone wants to know what are suggested as definitions for various types of iron, such as high strength iron, semi-steel, and so forth, it would be easy to get a copy from the A.S.T.M., or I would be very glad to give the information.

The definition proposed for high test cast iron was as follows: "High Test Cast Iron—A term formerly used to designate gray cast iron having a minimum tensile strength of 28,000 lbs. per sq. in." This term should now be considered obsolete, since A.S.T.M. A-48-32T definitely classifies gray iron castings.

A. VON FRANKENBERG[3]: Since 1916 we, in Germany, have been making high test gray iron, using a process iron.

We are producing pig iron with a fine graphite structure. This pig iron is produced in the blast furnace and it is superheated later and will keep the graphite structure after remelting in the cupola. This new iron is called "migra" iron and is not an alloy iron. Alloys are very expensive in Germany. You get a fine structure later on in the casting. It eliminates a lot of trouble in the foundry because you can use a large amount of steel scrap.

H. H. JUDSON[4]: In paragraph 17, the author says, "On the other hand, 2 per cent silicon was found to be, in general, too low (if connected with a 2.60 or 2.65 per cent carbon) for cupola irons produced by the usual method with steel charges."

We run a 2.50 per cent total carbon iron, with 1.50 per cent silicon, which is our standard analysis for large high pressure cylinders, with 2¼ inch wall thickness. We find definitely that 1.40 per cent silicon is satisfactory as is silicon as high as 1.80 per cent. We have, however, never reached 2.0 per cent silicon, but we have no trouble from shrinkage or anything else.

R. S. MACPHERRAN: The author states that he has had trouble with low silicon iron. We had the same trouble. It increased the shrinkage very materially. We found it so in castings of uneven section. We make all kinds of castings, often many tons a day of various sizes and shapes.

To get away from the trouble, we have raised the silicon to a little over 2 per cent and have kept the carbon as near 2.75 to 2.90 per cent as possible. Our practice is the same as that of Mr. Lenoine. We do not find that the increase of the silicon affects the strength badly. It does give it a more general use. It is easier to use in all kinds of work.

MEMBER: I would like to ask the composition of the pig iron which Mr. Von Frankenberg is using which is giving those characteristics to the castings that he mentioned.

A. VON FRANKENBERG: We are making pig iron of all kinds. Possibly we are making the hematite quality which is very low in phos-

[3] Deutsche Eisenwerke, Mulheim-Ruhr, Germany.
[4] Goulds Pumps, Inc., Seneca Falls, N. Y.

phorus and very high in total carbon. Most of this iron is used for making automobile cylinders and on account of the high total carbon content this iron is very fluid. You will have a fine structure after the melting in the cupola.

We are making about 2 per cent silicon and 3.9 to 4 per cent total carbon and the manganese is about 0.55 per cent, the phosphorus and sulphur are very low, depending on the coke you are using in the blast furnace.

At this time, we are making foundry iron with the normal amount of phosphorus and a little higher amount of silicon. Also, we are using a little scrap, but not as much as 50 per cent. It is about 25 or 30 per cent. That makes a cheap mixture. We are using other scrap, gray iron scrap, and then we put this pig iron in the cupola. We get very good results. That is mostly in very thin sections in the automobile cylinders.

MEMBER: Do you depend on the pig iron or on the superheating of the metal after making the mixture, to get the fine structure?

A. VON FRANKENBERG: I can only tell you the special way that we get this iron. This is the first time we have attempted that in Germany in making this type of iron in the cupola. We superheat all the material in the cupola. We get a high temperature and we guarantee the tensile strength for over 46,000 lbs. per sq. in. We superheat the material after coming from the blast furnace in the special way I mentioned, but I cannot tell you exactly how it is done.

MEMBER: What temperature do you heat the iron to?

A. VON FRANKENBERG: It depends on the analysis and how it comes from the blast furnace. The average temperature will be about 1450 degrees Cent.

R. P. LEMOINE, (*Reply to Discussion Submitted in Writing*): The author is very thankful to Mr. MacPherran for the appreciative words he had in presenting his paper and wishes to reply to some points raised during the discussion.

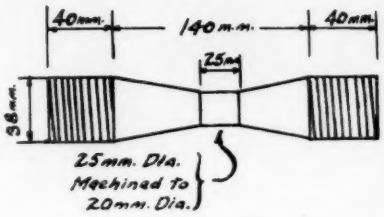
The impact resistance of pearlitic irons has been tested at least roughly with the normal drop hammer which is still in use for some specifications in the author's country. This impact test is known to have no great accuracy but it can be used to compare at least qualitatively from a large number of tests different classes of pearlitic irons.

The author's experience about rusty steel scrap is that this material often gives an iron with poor fluidity or, better, an iron the fluidity of which drops down very quickly with the temperature.

High test iron for steam turbine cylinders is generally alloyed with some chromium (0.20 to 0.40 per cent) and the silicon content is kept as low as possible following the shape and thickness of the castings. It is often limited to 1.80 per cent.

Results of mechanical tests have been omitted in the paper because the author has mostly in his notes figures related to Fremont tests which are in favour in his country but would not probably have been of much interest for his American colleagues.

He had however some tensile tests made from separately cast bars




shown by the sketch. With the following composition of iron: Total carbon, 2.62 per cent; silicon, 2.15 per cent; and manganese, 0.56 per cent, the results were all between 52,000 and 55,000 lbs. per sq. in.

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